REVIEW OF 2002
12 KM MM5 MODEL RESULTS

FINAL REPORT

Government
of Alberta

Review of 2002
12 Km MM5 Model Results

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EXECUTIVE SUMMARY

As part of a previous contract, RWDI was retained by Alberta Environment (AENV) to:

a) produce a subset of Mesoscale Model version 5 (MM5) output files at 12 km resolution covering the Province of Alberta based on model outputs for the 2002 model year provided by Environment Canada Prairie and Northern Region (EC); and

b) develop a Multi-Model Extraction Utility (MMEU) that can be freely distributed and used with the aforementioned MM5 subset to generate input files for use with a suite of air quality models. Details are available from the following websites: http://environment.gov.ab.ca/info/library/7696.pdf; and, http://environment.gov.ab.ca/info/posting.asp?assetid=7696&searchtype=asset&txtsearch=mm5. AENV has since retained RWDI to perform the following tasks under a separate contract:

Task 1. Review / evaluate the 2002 Environment Canada MM5 outputs over the Alberta subset domain.

Task 2. Run the MM5 model for three consecutive years at 12-km resolution covering the MMEU domain.

Task 3. Update the MMEU software solution to enable it to ingest and provide outputs using the new MM5 data set developed under Task 2.

The remainder of this document focuses strictly on the results of Task 1 and serves as a guidance document on the use and interpretation of the 2002 Environment Canada MM5 subset supplied by Alberta Environment with MMEU (Version 2006.03.03).

1.0 BACKGROUND

The purpose of this review is not to perform a comprehensive, statistical model evaluation of the 2002 dataset produced by Environment Canada. Rather, the purpose is to review the overall performance of the model in a general sense for a limited number of key parameters and to address some issues related to the data that were forward to RWDI by AENV. From this analysis, conclusions and general "usage notes" have been formulated.

2.0 METHODOLOGY

The model evaluation was based on qualitative and quantitative comparisons between paired hourly model results and observations from eight surface and two upper air stations. Environment Canada surface stations selected for the analysis were chosen to provide geographic coverage, with a bias towards areas where air quality modelling is likely to be performed. Although the focus of the evaluation was on the surface layer, a qualitative assessment of model performance aloft was also performed using data from two upper air (balloon) stations. The stations used are listed in Table 1 and shown geographically in relation to the MMEU domain in Figure 1 (blue symbols and font represent surface stations; red represents upper air stations).

Table 1. Name and coordinates (Latitude / Longitude) for meteorological observing stations used in the evaluation of Environment Canada's 12 km resolution MM5 outputs for 2002 as adopted in MMEU

Observation Station	Latitude (N)	Longitude (W)
Calgary Airport	51° 6.600'	114° 1.200'
Edmonton Airport	53° 19.200'	113° 34.800'
Edson Airport	53° 34.800'	116° 28.200'
Ft. McMurray Airport	56° 39.000'	111° 13.200'
Grande Prairie Airport	55° 10.800'	118° 53.400'
High Level Airport	58° 37.200'	117° 9.600'
Lethbridge Airport	49° 37.800'	112° 48.000'
Slave Lake	55° 17.400'	114° 46.800'
Stony Plain (upper air)	53° 33.000'	114° 6.000'
Great Falls (upper air)	47° 27.000'	111° 22.480'

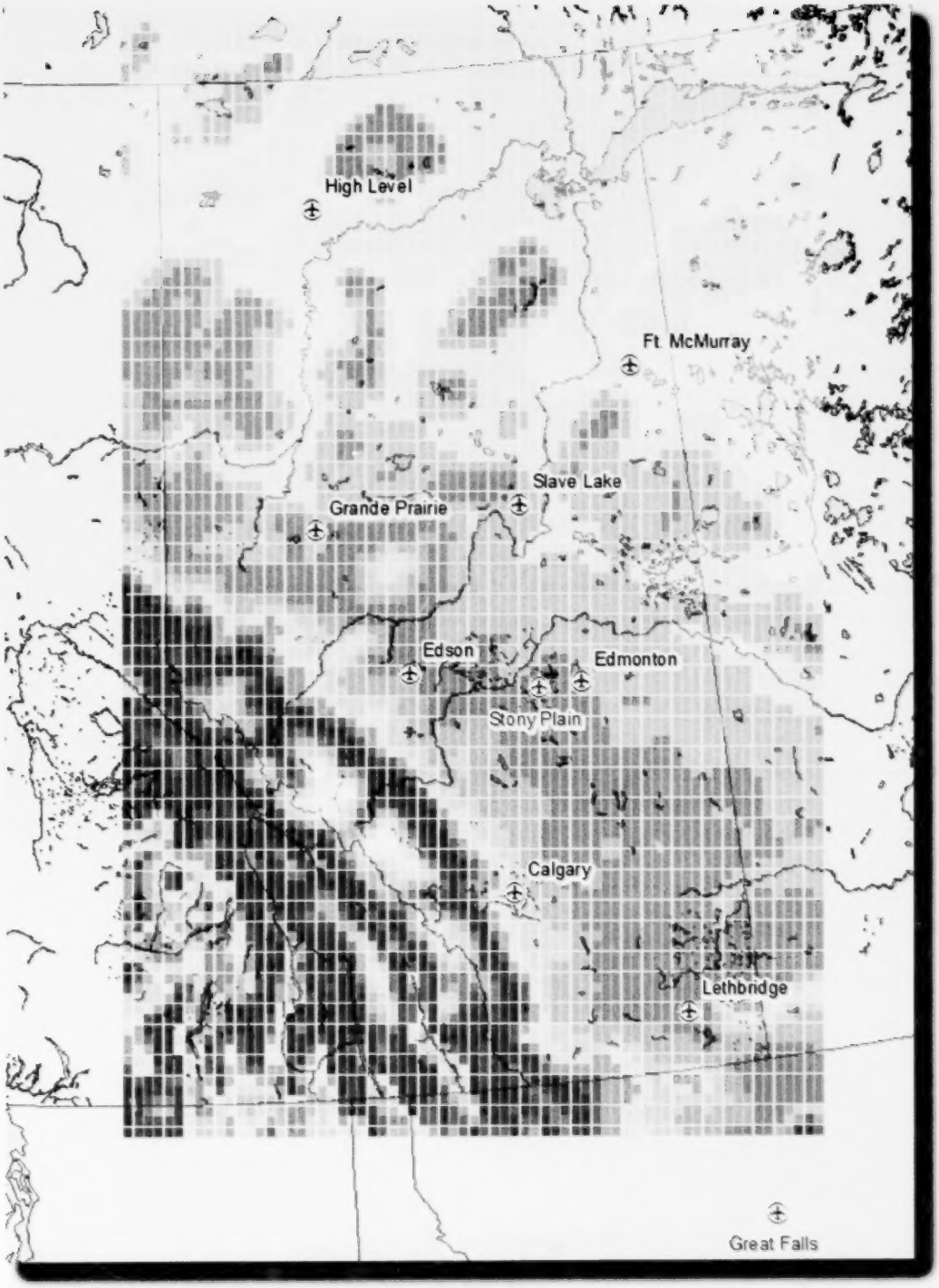

Figure 1. **Geographic coverage of the MMEU domain and location of meteorological observing stations used in the evaluation of Environment Canada's 12 km resolution MM5 outputs for 2002 as adopted in MMEU (blue = surface station; red = upper air).**

The model evaluation was based on four parameters that relate to key meteorological inputs required for dispersion modelling: dry bulb temperature, wind speed, wind direction, and relative humidity. Dry bulb temperature, wind speed, and direction were extracted directly from MM5 results; relative humidity was calculated based on the vapour mixing ratio from the MM5. The review process involved the following tasks:

1. Perform a qualitative review of the MM5 model options (nesting, nudging, physics options) adopted by Environment Canada.

2. Extract and tabulate model outputs and observations for eight surface observing stations and two upper air stations.

3. Produce station-by-station time series and 1:1 scatter plots from hourly results for both Winter (January) and Summer (July) months for the following (Appendix A):
   - Temperature
   - Wind Speed
   - Wind Direction
   - Relative Humidity

4. Produce domain-wide time series and 1:1 scatter plots from hourly results for both Winter (January) and Summer (July) months for the following (Appendix B):
   - Temperature
   - Wind Speed
   - Relative Humidity

5. Calculate simple performance statistics (Fractional Bias and Normalized Mean Square Error) on the domain-wide results for the winter and summer periods, as well as the entire year (i.e., annual statistics – no graphs produced) for the following parameters (Appendix B):
   - Temperature
   - Wind Speed
   - Relative Humidity

The following statistics were computed:

$$\text{Fractional Bias or } FB = \frac{\overline{C^s} - \overline{C^o}}{(\overline{C^s} + \overline{C^o})/2}$$

$$\text{Normalized Mean Square Error or } NMSE = \frac{\overline{(C^s - C^o)^2}}{\overline{C^s} \cdot \overline{C^o}}$$

where C^s = model prediction

C^o = station observations

6. Produce time series from hourly MM5 results and twice daily balloon data for both Winter (January) and Summer (July) months for the following parameters at 100m, 500m, and 1000m (Appendix C):
   - Temperature
   - Wind Speed
   - Wind Direction
   - Relative Humidity (MM5 results only)

An excerpt from Appendix A is provided in Figure 2 to assist the reader in interpreting the results provided in the various appendices. Plots from other parts of the analyses (domain-wide statistics, etc.) provided in Appendices B and C follow a similar layout.

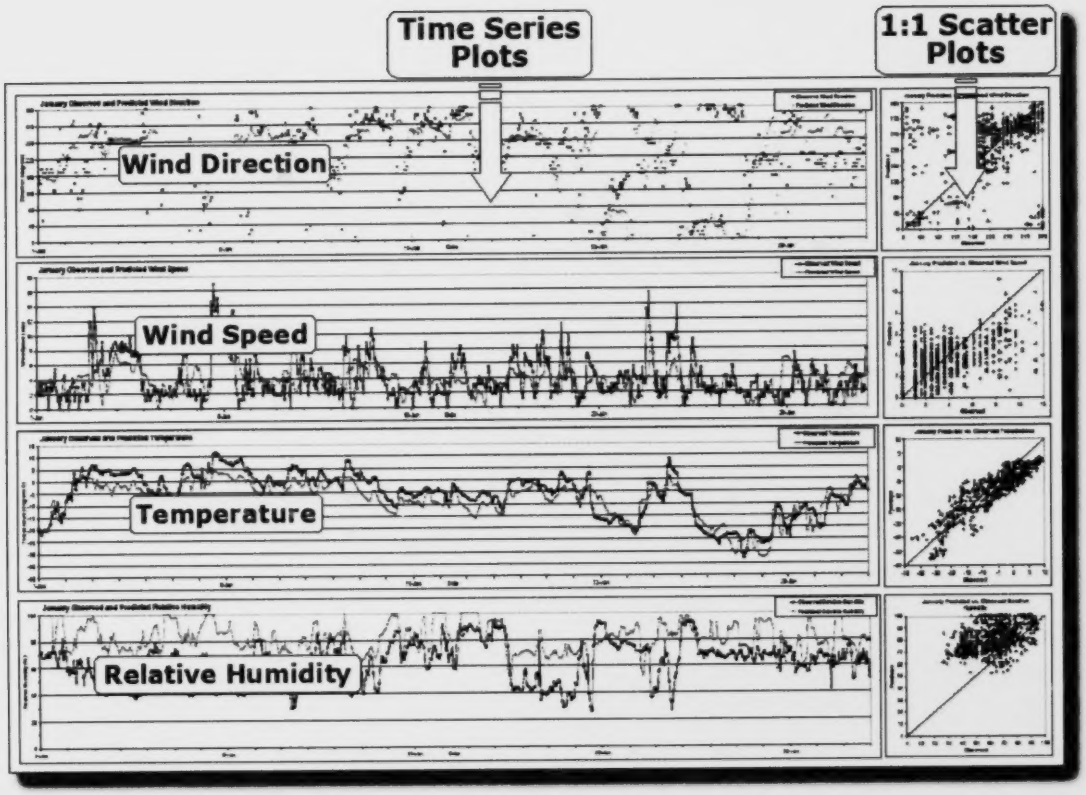

Figure 2. Sample time series and scatter plots.

3.0 MODEL RESULTS: DRY BULB TEMPERATURE - SURFACE

The plots in Appendix A indicate that the model overestimated daily maximum temperatures in the summer at all stations. This appears to be due to an over-prediction of peak daytime temperature during a well-developed diurnal temperature cycle typical of clear sky, anti-cyclonic synoptic conditions. Overnight lows were simulated well at all stations.

The model slightly underestimated temperature at all sites in the winter. Under-predictions are not associated with a diurnal pattern but appear to be associated with longer, larger scale synoptic patterns that last several days.

These seasonal discrepancies in predicted temperatures are most likely the result of modelling artefacts associated with the selection of the Medium Range Forecast (MRF) planetary boundary layer (PBL) scheme (combined with other options), and input data quality issues from the 2.5 degree resolution NCAR/NCEP Reanalysis Project (NNRP or R1) data used by Environment Canada.

Using coarse resolution NNRP data as the primary input to MM5, without the addition of nudging (FDDA), has been demonstrated to result in these types of temperature biases in MM5 results (Salathé, 2007). In addition, as other MM5 modellers have noted, the MRF scheme consistently overestimates the height of the PBL, especially during the summer months. Experiments (ATMET Report, 2003) have shown this tendency to overestimate the depth of the boundary layer especially during the daytime hours. Overestimates manifest themselves in numerous ways, including too little moisture in the PBL and an overestimate of daytime temperatures in summer. Further, the Shallow Convection scheme was not used in either the 12 km or parent 36 km resolution domains. This likely resulted in an underestimate of non-precipitation clouds in the summer, hence an increase in solar radiation on the ground and an associated increase in temperature throughout the PBL.

Although the overall model performance is better, there is still a noticeable cold bias and lack of diurnal variability in the model results for the winter period. The primary cause is likely the 2.5 degree resolution NCAR/NCEP reanalysis data (NNRP). Analyses of NCAR/NCEP reanalysis data (Kalnay *et al.*, 1996) and a recent model evaluation (Salathé, 2007) suggest that there is a general bias towards cold temperatures in winter in this dataset, which in turn can create biases towards colder temperatures in the MM5 results.

Domain wide average temperatures show similar patterns (Appendix B). The computed Fractional Bias (FB) is negative in winter (indicating a general under-prediction) and positive in summer (depicting a generalized over prediction). The net effect is a slightly negative, domain-wide annual average FB.

The Normalized Mean Square Error (NMSE) for dry bulb temperature is higher in winter than summer. This is a result of the greater magnitude of FB for this period and also likely indicates a greater difference in station-observation pairs.

4.0 MODEL RESULTS: WIND SPEED AND DIRECTION - SURFACE

A comparison of model results with observations is complicated by the fact that observations of wind direction are recorded in 10's of degrees and wind speeds are recorded to the nearest km/hr. Model results, on the other hand, are available to the nearest tenth of a unit.

Paired model versus observed scatter plots for both wind speed and direction present a large degree of scatter for all stations (Appendix A). However, the time series plots suggest that the model predicted the majority of the larger scale wind flows and diurnal patterns relatively well. The one exception to these observations is for Calgary Airport.

Scatter plots for wind direction at the individual stations seem to show better agreement in the wintertime. The model tends to over predict wind speeds in winter, with the exception of Calgary where the opposite applies. The model generally under predicted wind speeds in the summer and failed to capture short duration, high wind speed peaks.

Predictions from stations to the north appear to show larger differences between the predicted and observed than stations to the south (with the exception of Calgary).

Domain wide statistics for wind speed indicate a positive FB for winter; and a slight negative FB for summer (Appendix B). The domain wide annual average FB for wind speed is near zero, suggesting that on an annual basis, wind speed is generally well represented.

The NMSE is higher for wind speed in the summer compared to the winter, pointing to a higher degree of variation between model results and observations in the summer.

5.0 MODEL RESULTS: RELATIVE HUMIDITY - SURFACE

The model significantly over-predicts relative humidity at all stations during the winter. This over-prediction is more evident for the more northerly stations. Conversely, the model under predicted relative humidity in the summer. Again, the predictions are worse for stations further to the north.

Time series for summer time humidity show strong diurnal patterns that are related to influences of temperature as well as total atmospheric water content. These same patterns are not evident for the winter, which is to be expected.

Domain-wide time series show that predicted RH is less than observed even when predicted and observed temperatures are in relative agreement. This demonstrates that the under-prediction of RH by the model is related to there being not enough water vapour in the model atmosphere rather than strictly a temperature dependence.

Domain wide average scatter plots show almost all points falling above the 1:1 reference line in the winter, indicating a strong positive bias in the model predictions. Conversely, most points fall well below the 1:1 reference line in the summer.

Domain wide annual average FB for relative humidity is nearly zero, which indicates that the seasonal over and under predictions tend to equal out over the course of the year.

6.0 MODEL RESULTS: UPPER AIR

A comparison of model results to upper air data was performed based on two stations: Edmonton / Stony Plain, Alberta; and, Great Falls, Montana. Although Great Falls is not in Alberta it falls within the parent MM5 domain from which the MMEU meteorological data were derived and as such is felt to be relevant.

The evaluation was based on a comparison between modelled and observed values of wind speed, wind direction, and temperature for three vertical levels: 100m, 500m and 1000m. Unlike the MM5 results, which are available hourly, upper air observations are only made twice daily, at 1200 and 0000 GMT (Greenwich Mean Time). In addition, observations from balloons are not recorded at pre-defined vertical levels; rather, observations are recorded at certain pre-defined and intermediate pressure levels (not specified heights above ground). Therefore, the exact height from the MM5 model outputs (based on the model's vertical grid definition) is not always available in the upper air observations. This means that the height from the corresponding observation measurements typically differ by 10 to 100 meters from the height that is extracted from the model.

Based on these issues, no statistics were computed. Instead, time series graphs depicting model results (pink symbols and lines) and observations (blue diamonds) were used to perform a qualitative assessment of the overall model performance. Representative graphs for summer (July) and winter (January) periods are provided in Appendix C.

Wind directions in the winter are replicated well at all levels. Wind directions in the summer are more variable, particularly at lower levels. This is because meteorological conditions during the winter are generally driven by broad synoptic conditions that are well represented by MM5. Summertime winds at lower levels are more dependent on boundary layer dynamics associated with stronger thermal affects (surface heating) during the summer, which are not as well represented in MM5. This causes more variability between model results and observations during the summer months. Despite the greater amount of 'noise' in the summertime results, the wind patterns are captured fairly well overall.

Wind speeds are well represented at all times and levels with the model reproducing both high and low wind speed patterns with no apparent biases. The model also appears to have captured lower overnight winds due to stable night-time conditions in summer as well as high wind speed events due to frontal passages in winter.

Summertime temperatures and diurnal patterns are predicted well at all levels. However, aside from a short period in early January, the model seems to underestimate wintertime temperatures at all levels. This could be associated with grid resolution issues and / or the fact that the upper air observations being used in the comparison are from a slightly lower elevation than the model outputs, as discussed above. The early January period shows a marked over-prediction at the 100m level for Edmonton / Stony Plain, presumably associated with the over prediction of the intensity of a warm front passage. This is likely the result of the model bringing more warm air to ground than what actually occurred. In reality, cold surface air is not easily dislodged by the passage of less dense, warmer air aloft. Based on this, the timing of temperature changes at lower levels during frontal episodes might not be accurately represented by the model (i.e., cold air from aloft was introduced too soon in the case described above). Similar results are seen in the data for Great Falls.

7.0 CONCLUSIONS

In general, the model predictions for wind speed, direction, and temperature are adequate both at the surface and aloft. Temperatures are predicted fairly well throughout the domain. However on a seasonal basis, the model results within the boundary layer are generally too cool and moist during the winter and too dry and warm during the summer. The use of coarse resolution (2.5 degree) NCAR/NCEP Reanalysis Project (NNRP) data as the primary input to MM5 appears to be the primary cause for these discrepancies. These problems were likely exacerbated by the selection of the MRF PBL scheme and by omitting the shallow convection scheme during model execution. Although 3-Dimensional analysis nudging was performed for the parent 36 km resolution domain, no surface analysis nudging was performed for either the 36 km or 12 km domains. Theoretically, FDDA (Four Dimensional Data Assimilation) with surface nudging could help to reduce these biases in the 12 km results.

Wind speed and direction depict a fair degree of scatter but tend to align well with the observed trends on an hour-by-hour basis (time series), both at the surface and aloft. Model performance is somewhat better in the southern part of the domain.

Although the model performance for relative humidity at the surface appears reasonable on an annual average basis, it is in fact quite poor on a seasonal basis. The under-predictions in summer and over predictions in winter tend to cancel out in the annual statistics.

For coarse resolution, annual air quality modelling scenarios, Environment Canada's 12 km resolution MM5 output for 2002 as adopted within MMEU should be adequate. However, modellers should bear in mind the following points when using the 2002 MM5 dataset for air quality or meteorological modelling. This holds true for modellers wanting to use the MM5 outputs either through the MMEU utility, or as a standalone dataset.

a) Underestimations of wind speed in summer could lead to reduced turbulence and hence conservative dispersion predictions. Conversely, the overestimation of wind speeds in winter may cause air quality dispersion models to predict somewhat on the low side. Wind speed errors are generally relatively small, however, and the annual bias is virtually zero. Therefore, although there are some variances between the modelled and observed on an hourly basis, annual dispersion model results should not depict any particular bias due to wind speeds from MM5.

b) Errors in the prediction of humidity could affect secondary chemistry and wet deposition (depending on the air dispersion model and physics / chemistry algorithms being used). Warmer and drier summer predictions may potentially increase dispersion and reduce wet deposition, which may result in an underestimate of short-term maximum ground level pollutant concentrations and / or total deposition. On the other hand, lower predicted temperatures in the winter may lead to more stable atmospheric conditions, causing an overestimate of ground level concentrations and deposition at this time of year. Further, humidity is a factor in the growth of hygroscopic (aqueous-phase) secondary particulate matter and therefore (depending on the air quality / photochemical model being used) affects the prediction of total particulate matter and calculations pertaining to light

extinction or visual range (i.e., haze). As with relative humidity itself, this issue will be more prevalent in northern parts of the domain.

c) To minimize some of these biases, a combination of MM5 with available surface observation data should be applied in air quality dispersion modelling applications. With this approach, models will be able to take advantage of the 3-D wind fields from MM5, while correcting for near surface wind and temperature biases using local observation data.

8.0 REFERENCES

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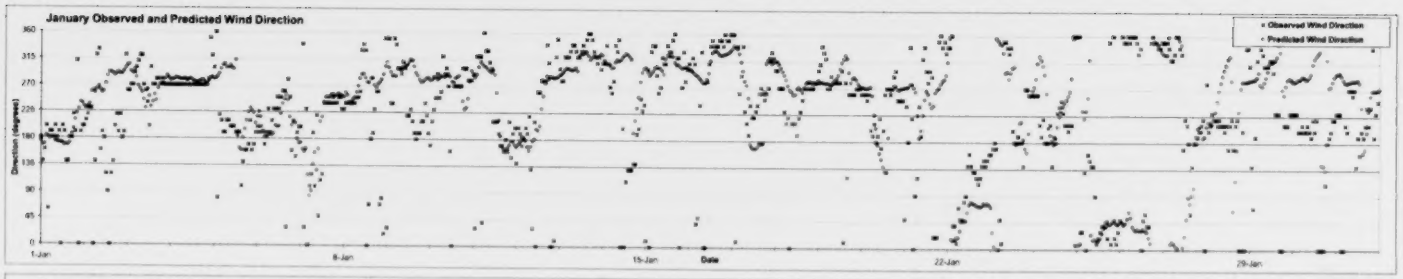
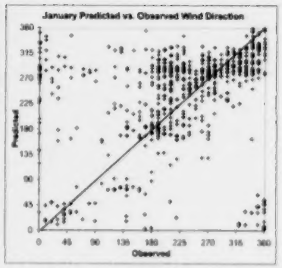
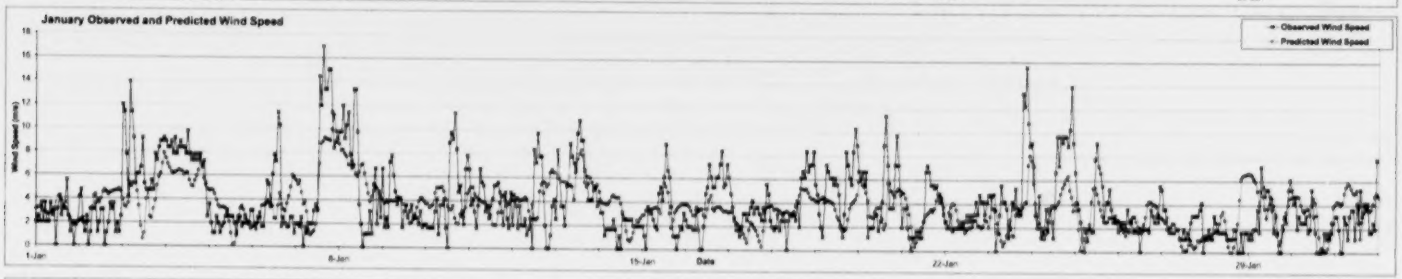
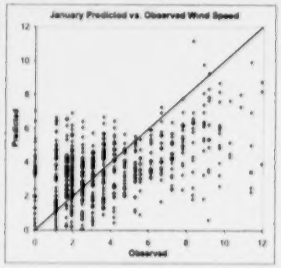
APPENDIX A

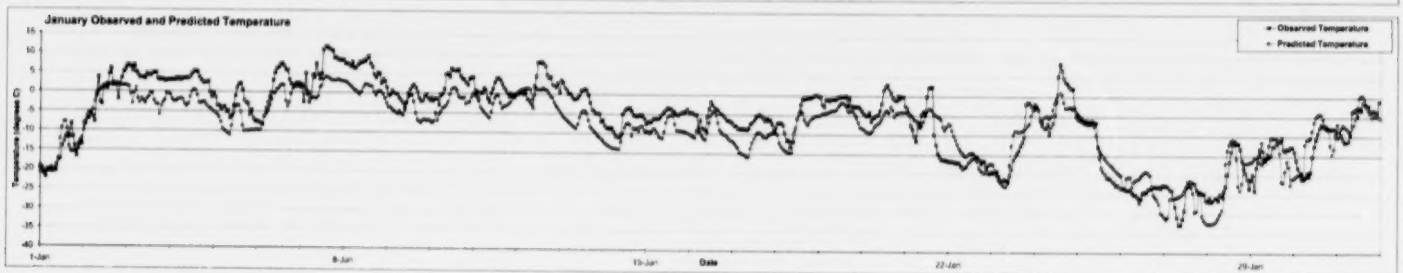
STATION: Calgary 12km MM5

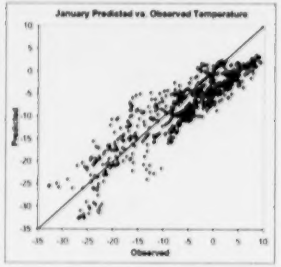


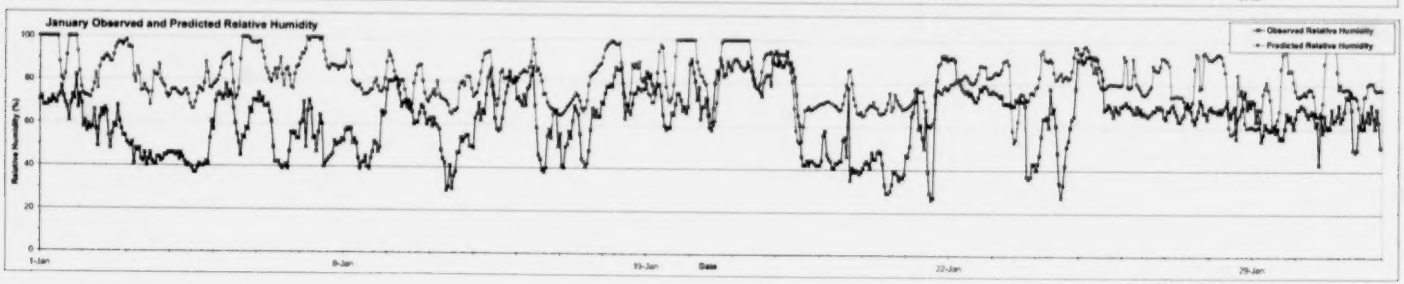


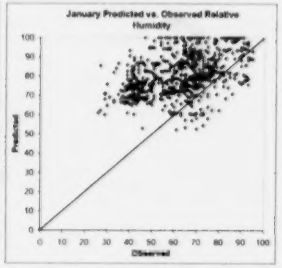




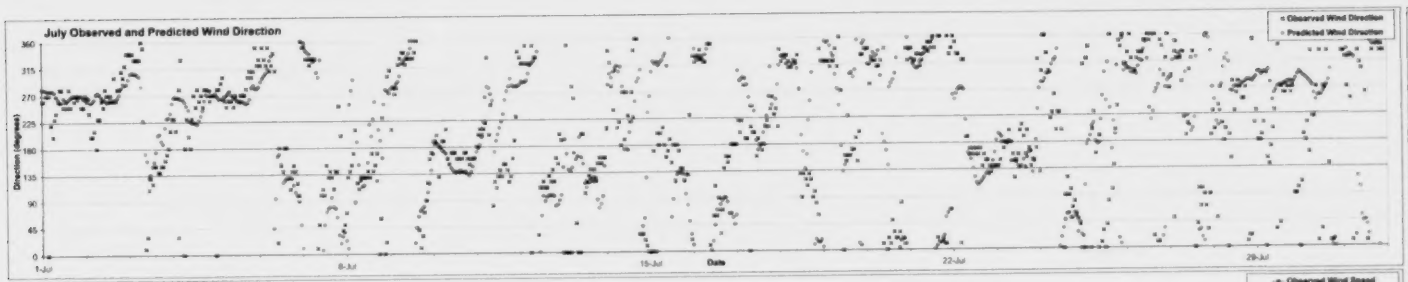


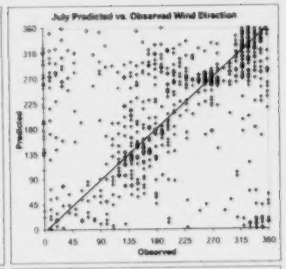


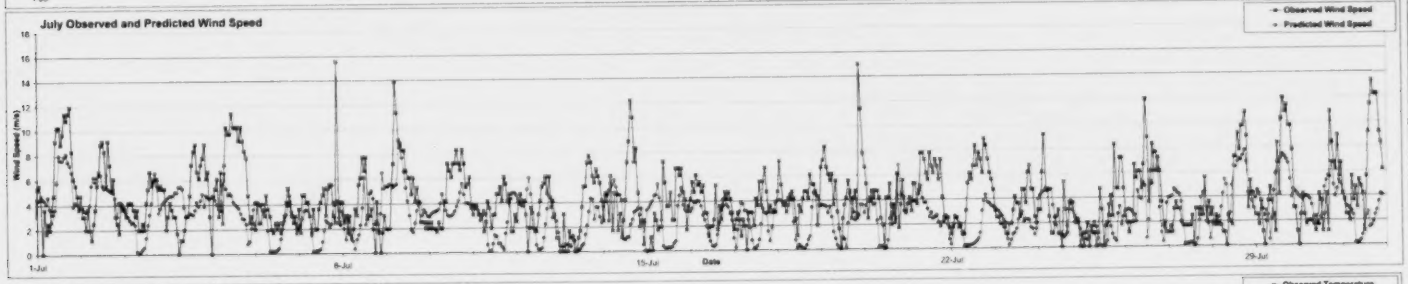


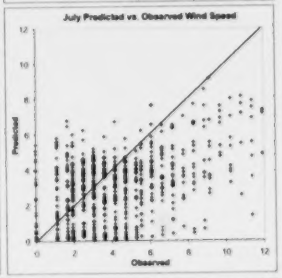


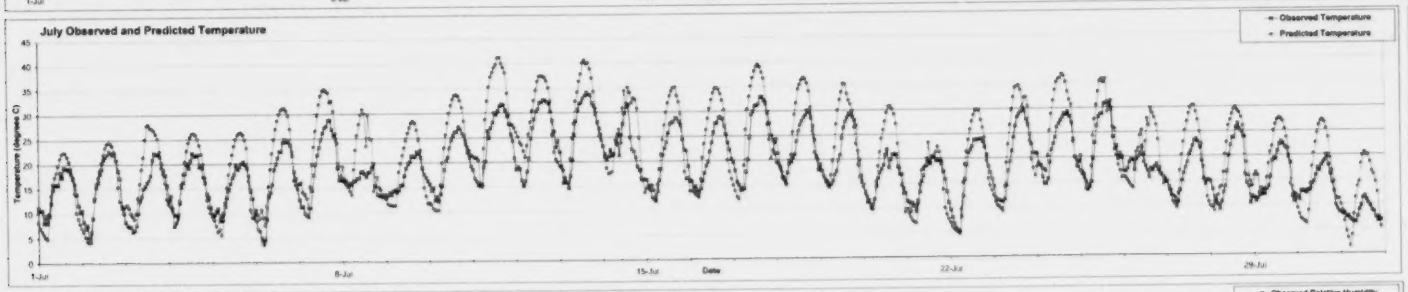
STATION: Calgary 12km MM5

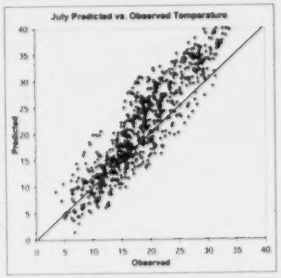


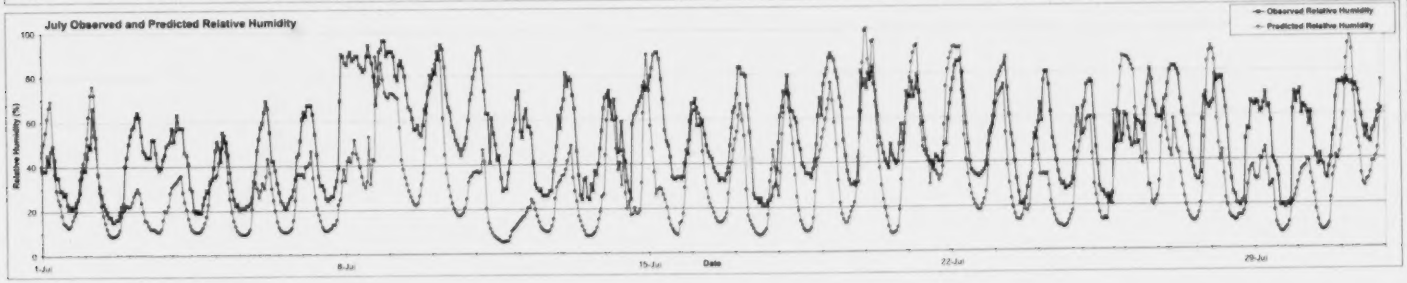


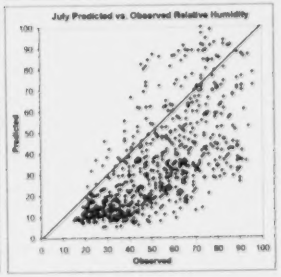












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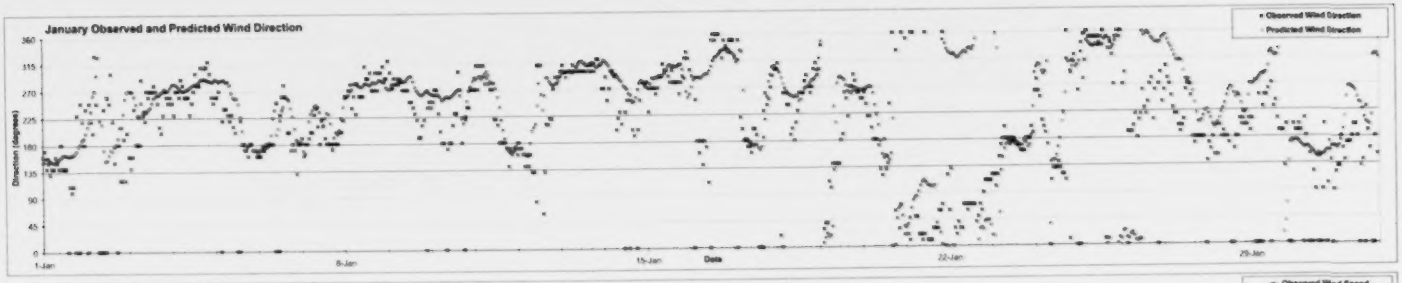
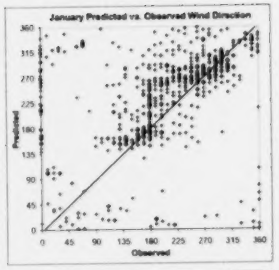
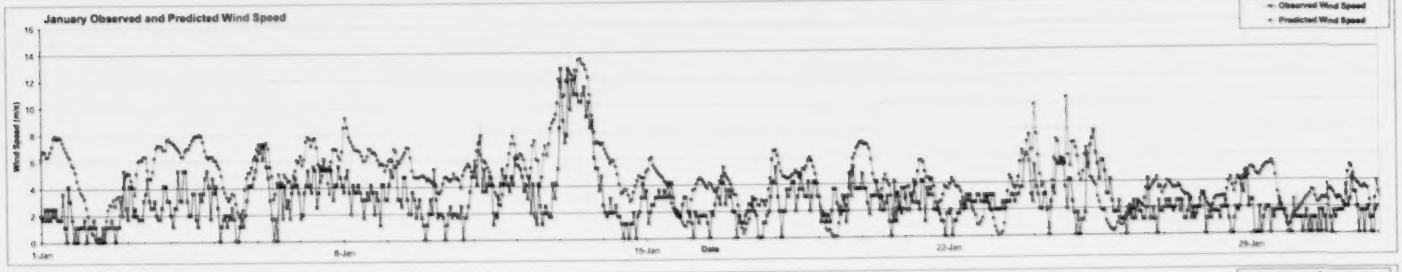
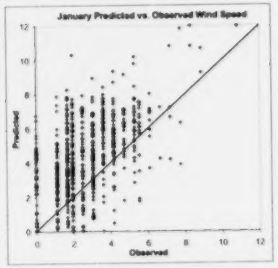
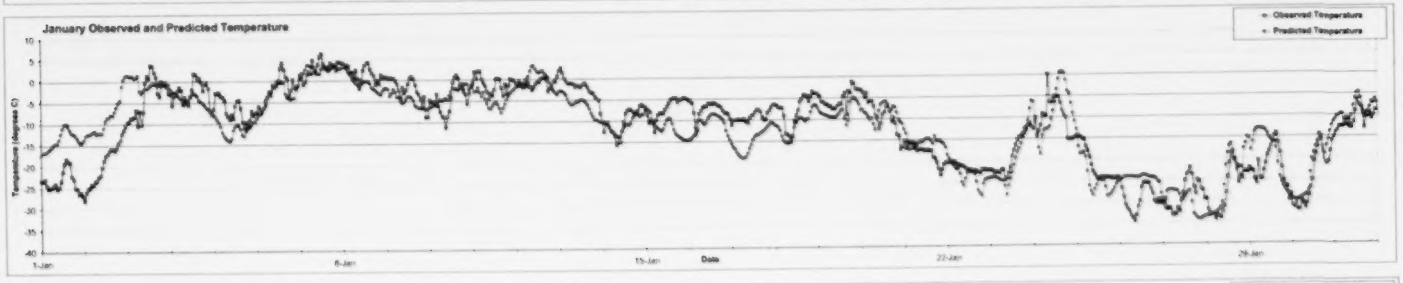
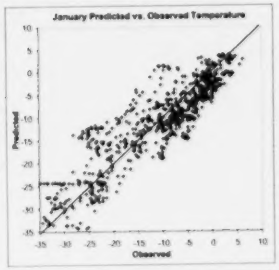


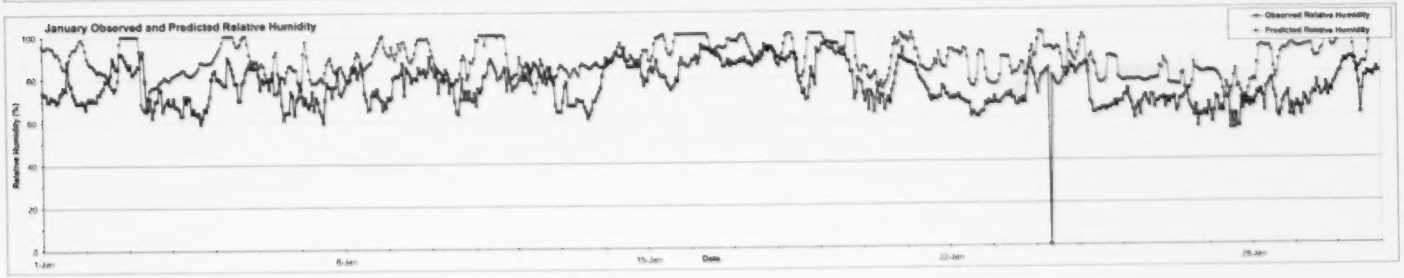


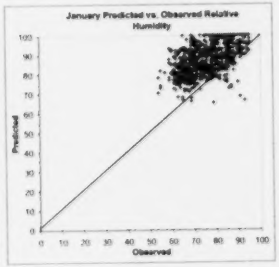




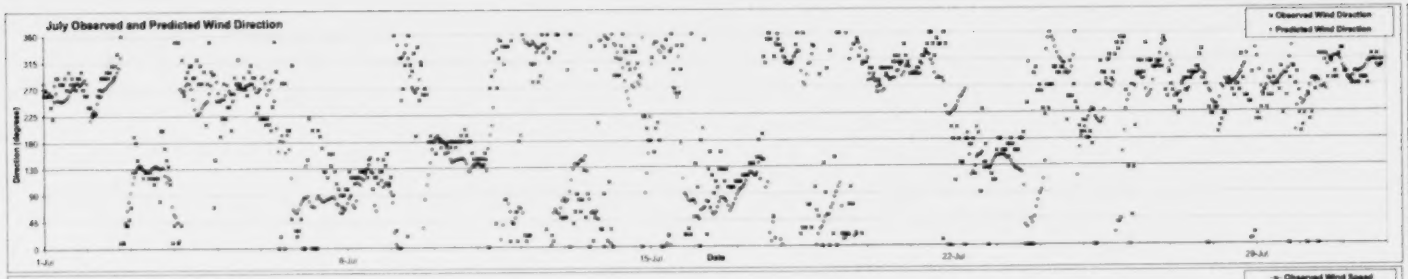


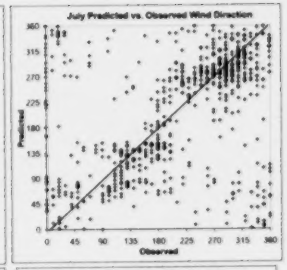


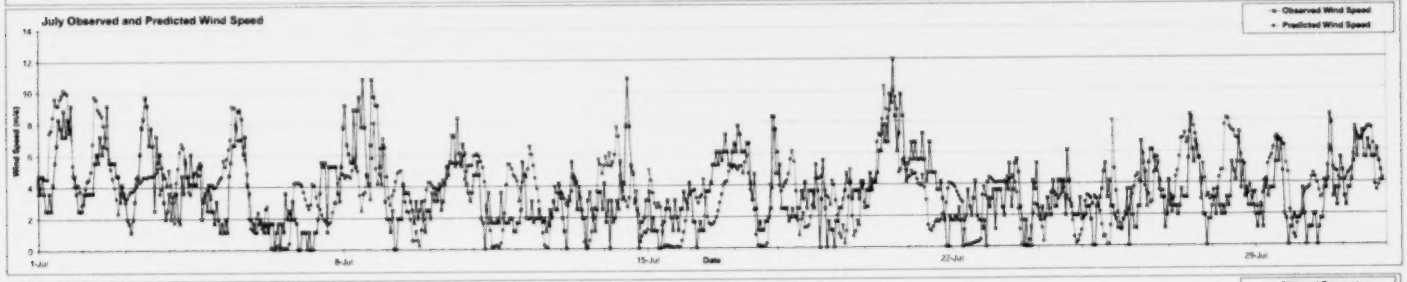


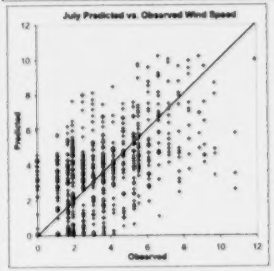


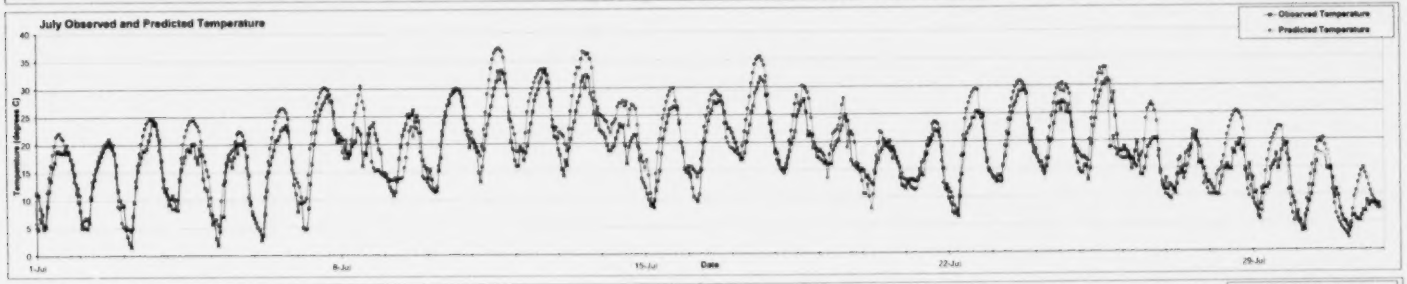
STATION: Edmonton 12km MM5

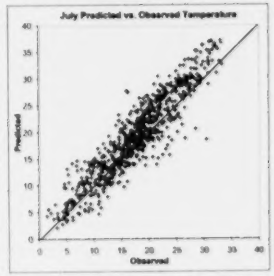


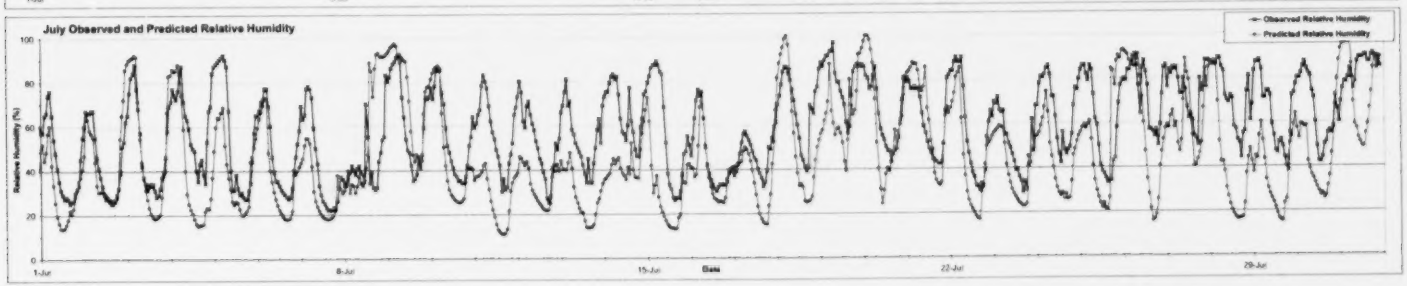


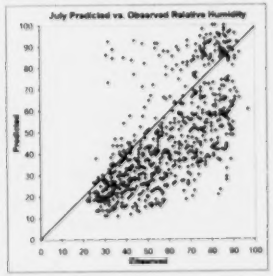




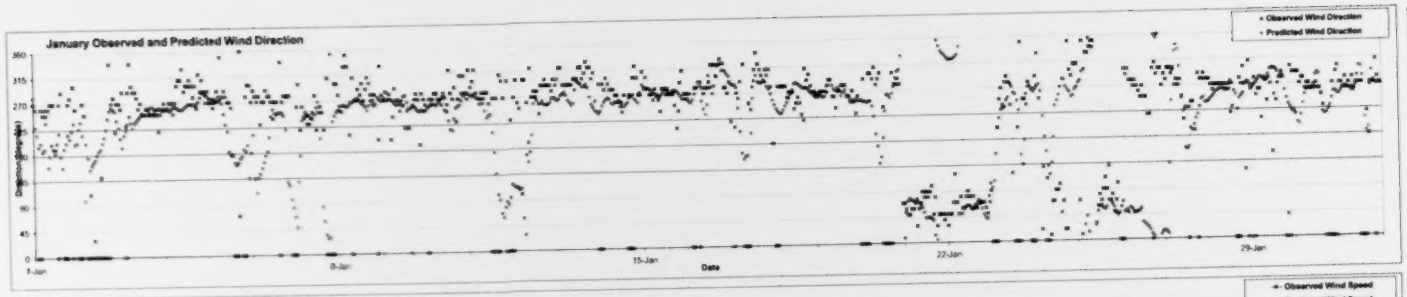


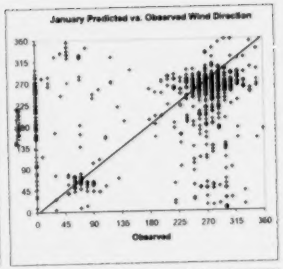


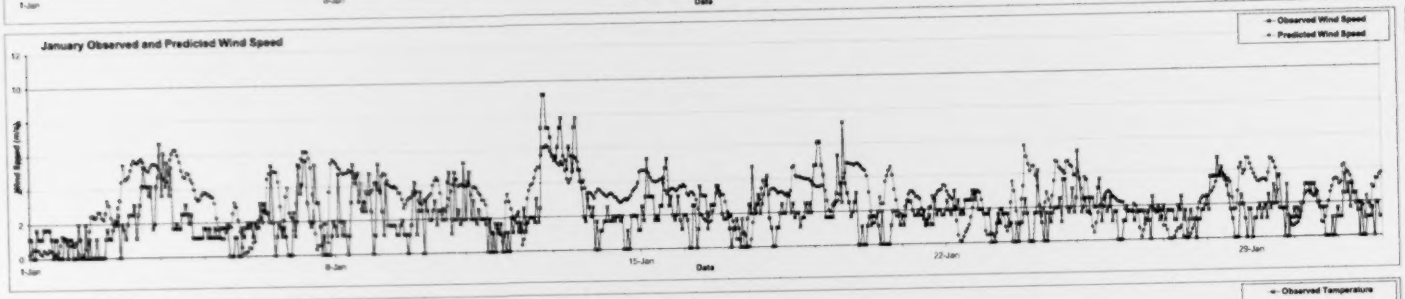


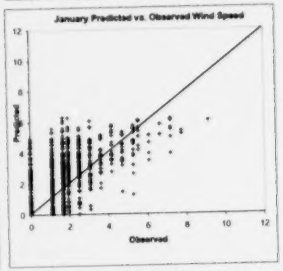


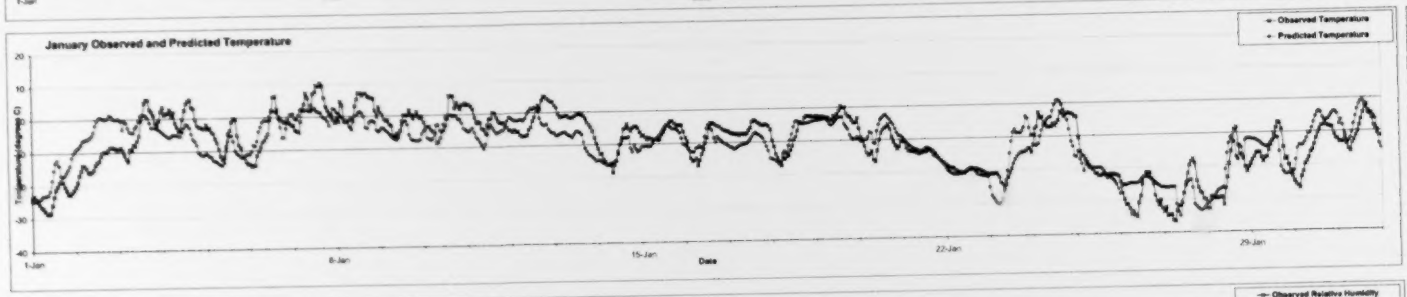
STATION: Edson 12km MM5

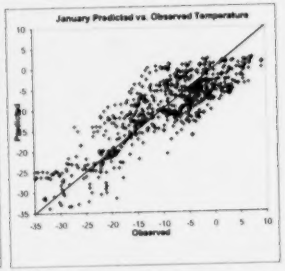


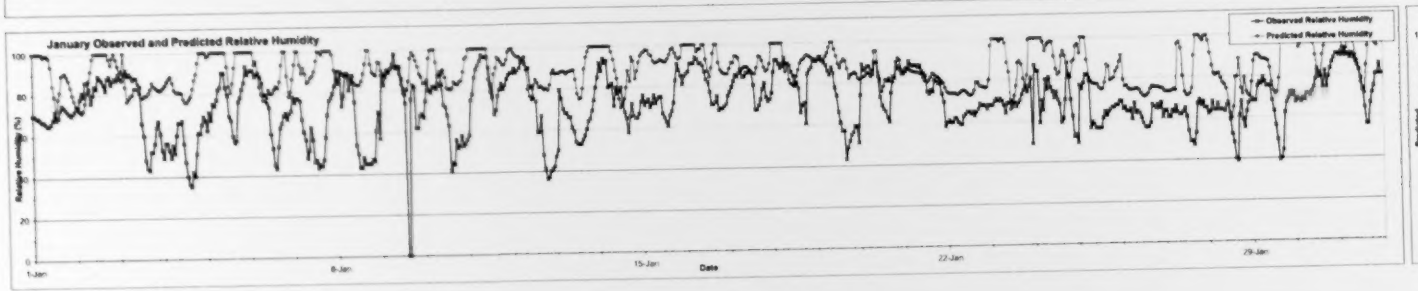


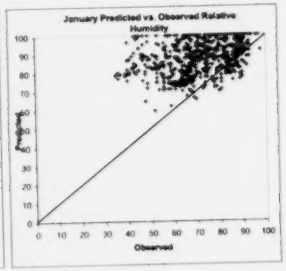




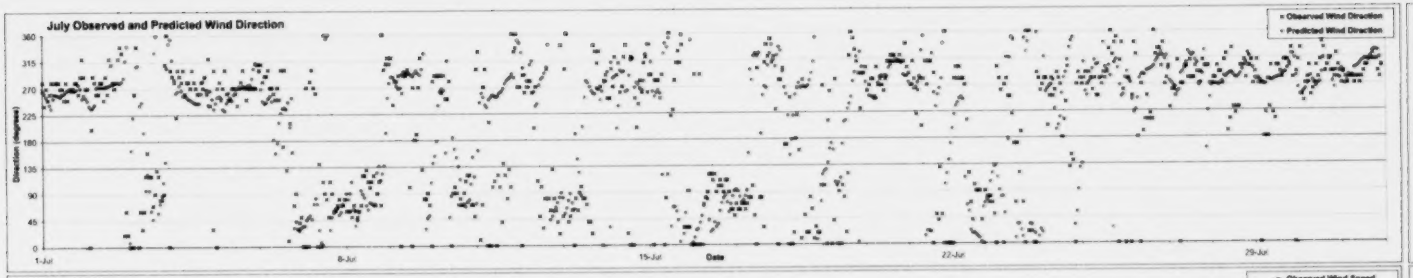


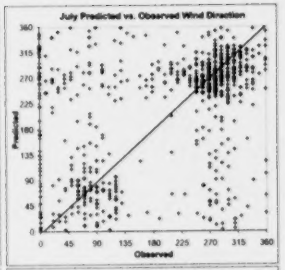


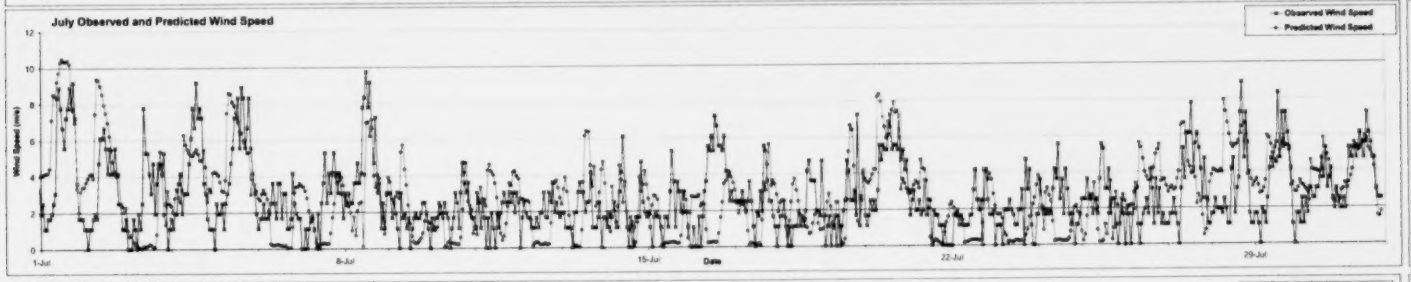


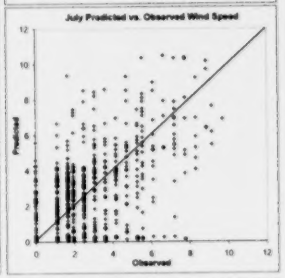


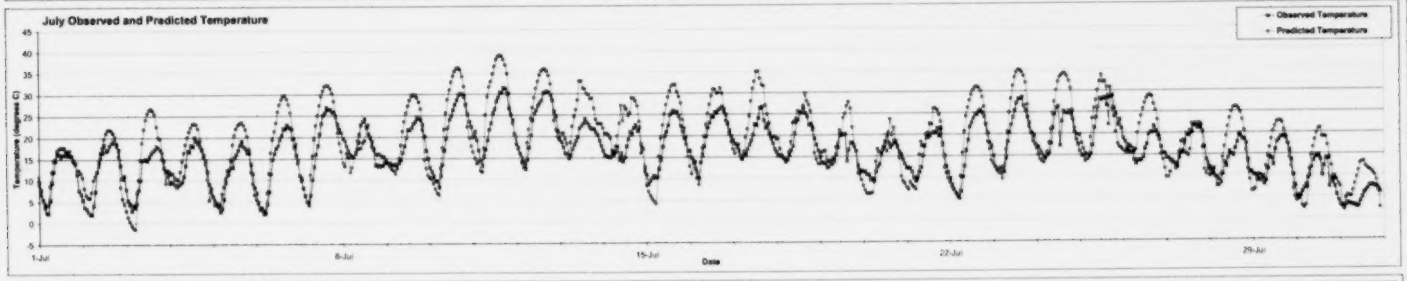
STATION: Edson 12km MM5

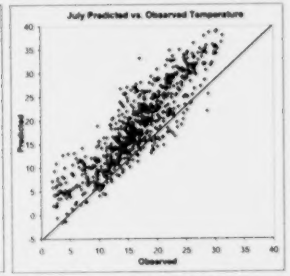


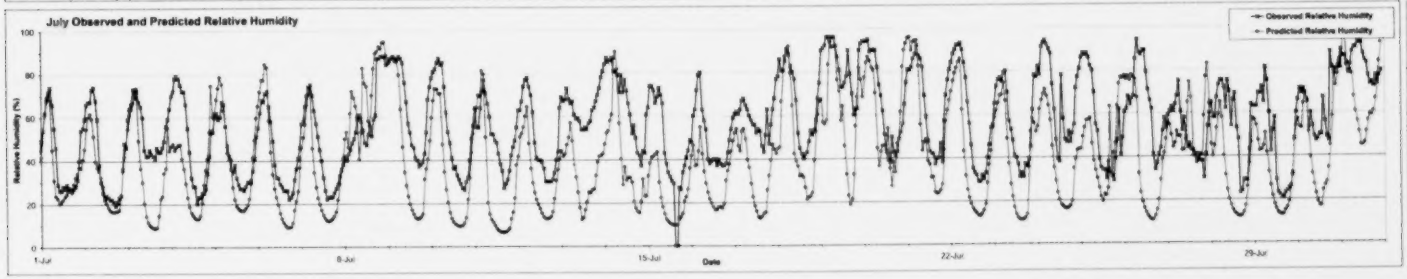


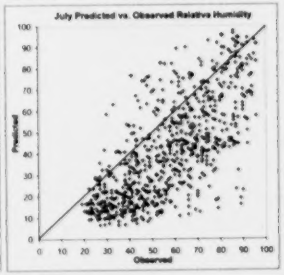




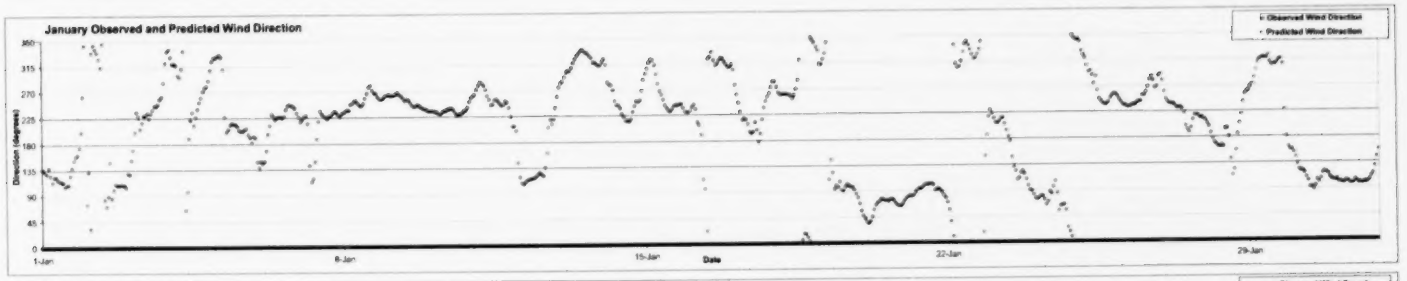


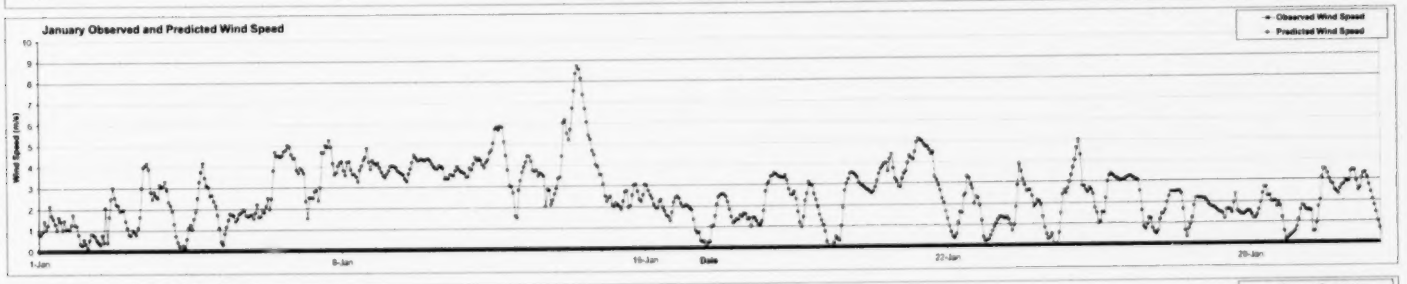


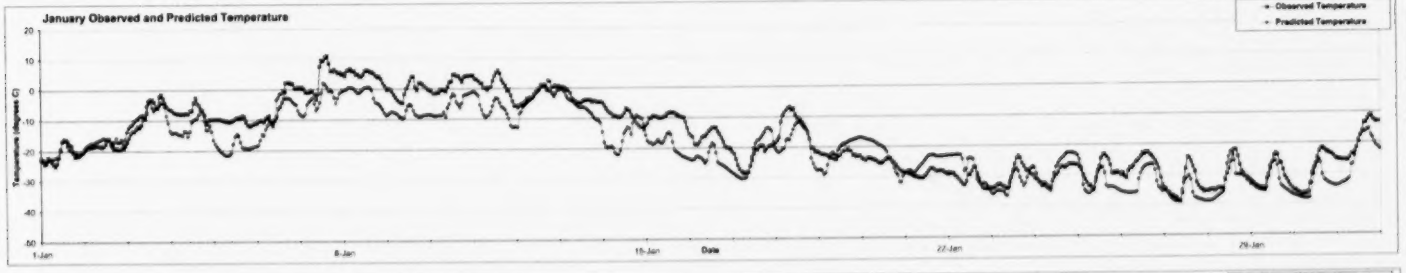


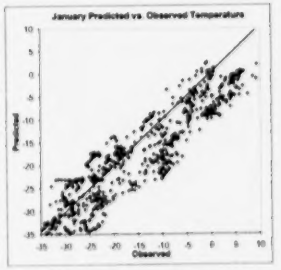


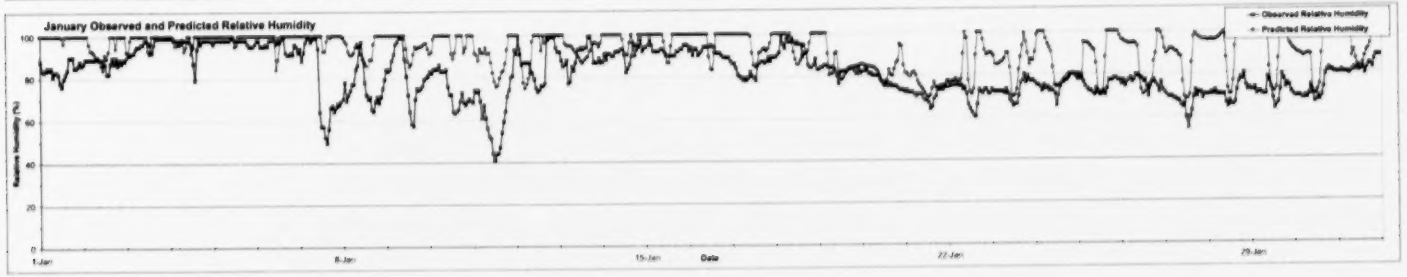
STATION: Ft McMurray 12km MM5

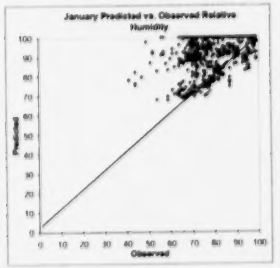




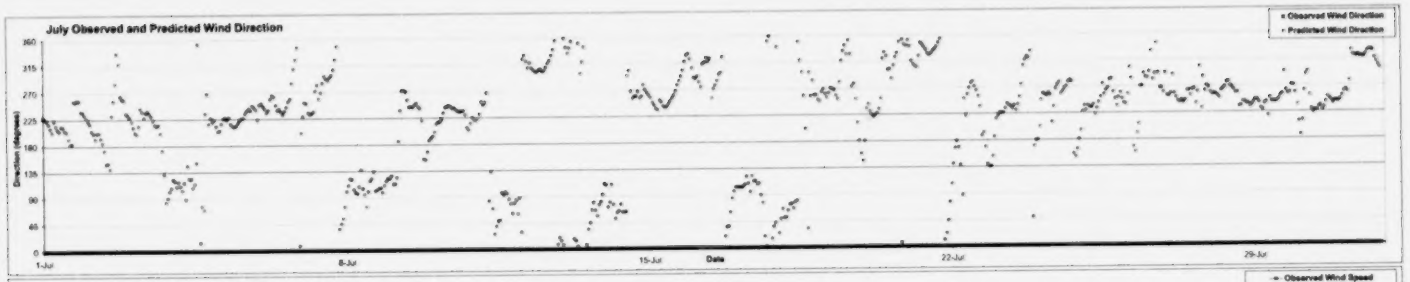


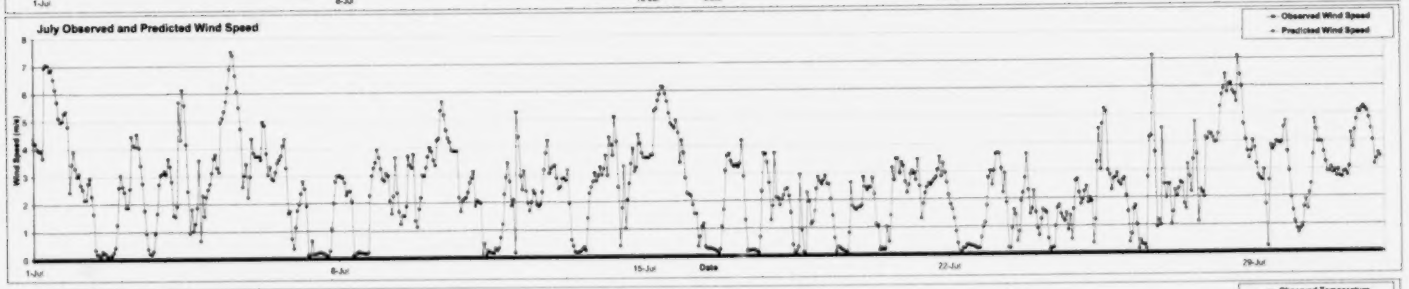


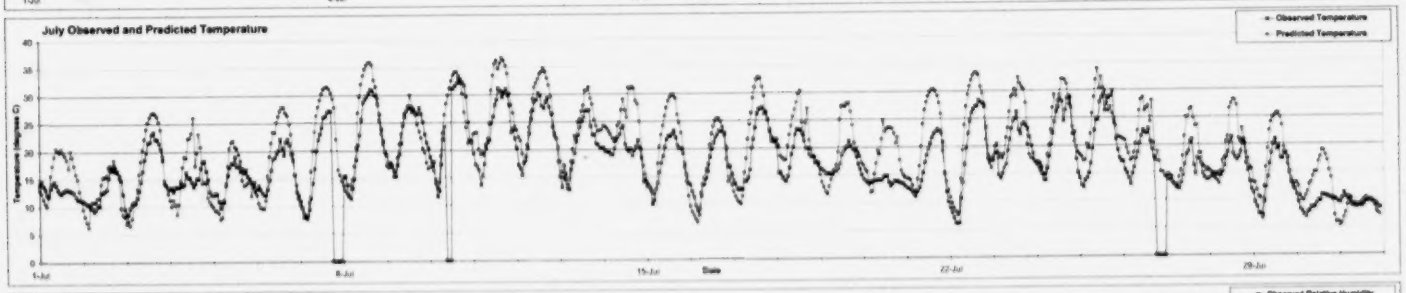


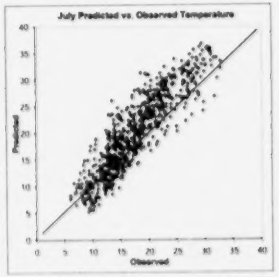


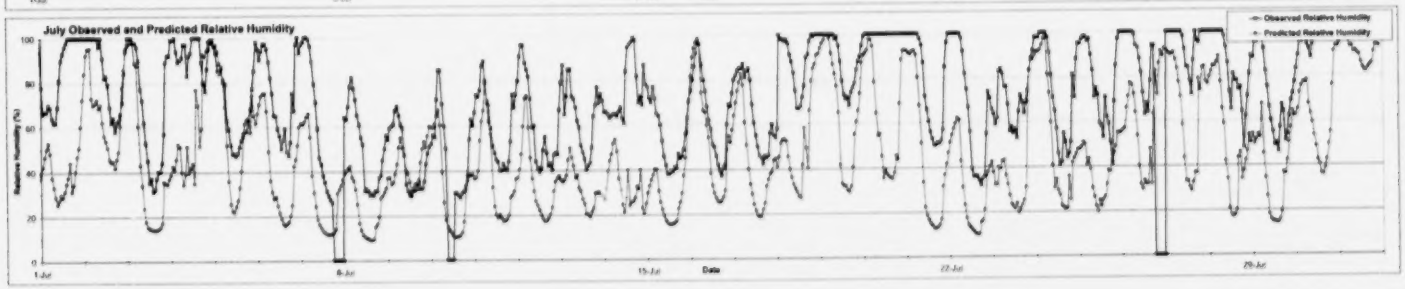
STATION: Ft McMurray 12km MM5

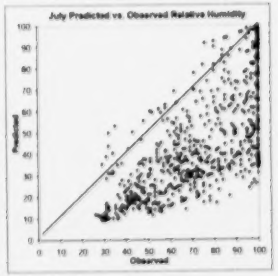




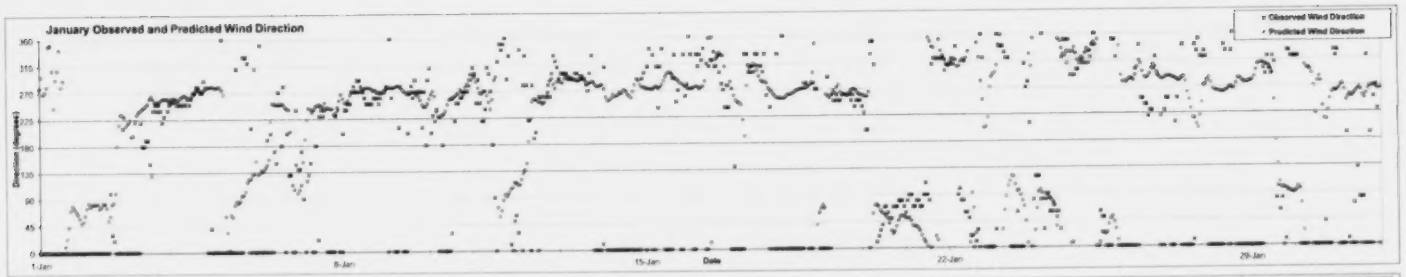


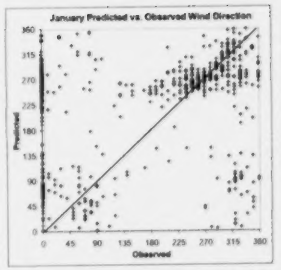


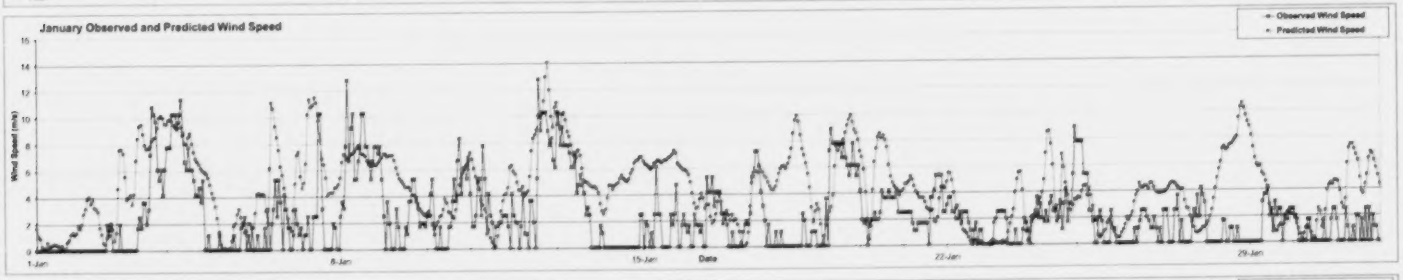


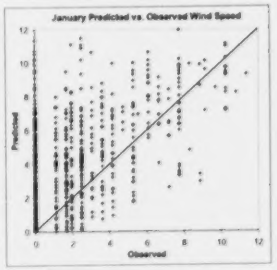


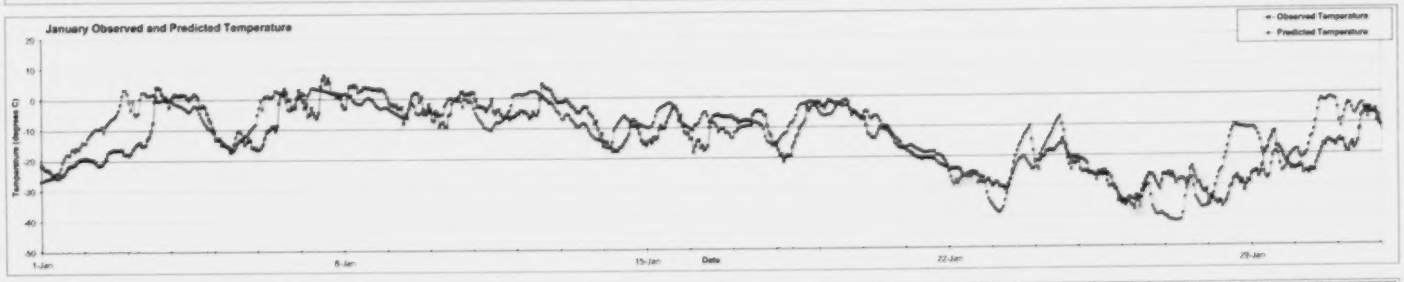
STATION: Grande Prairie 12km MM5

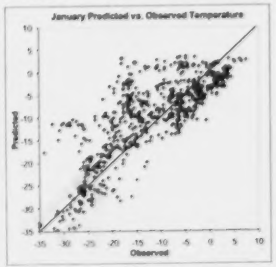


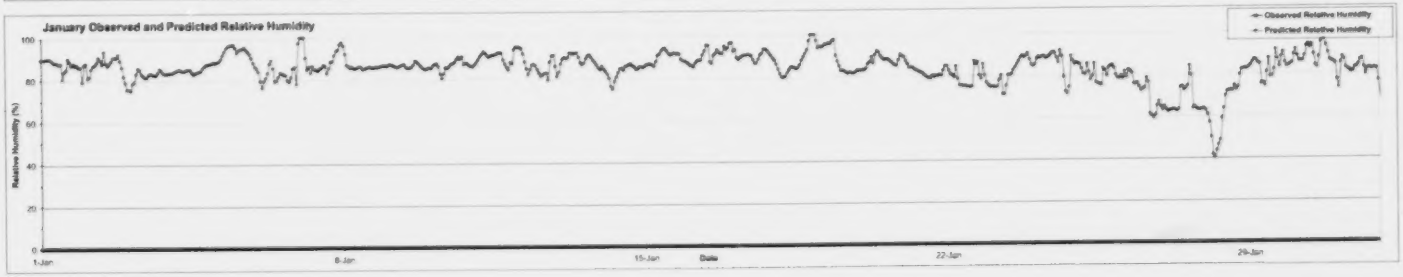




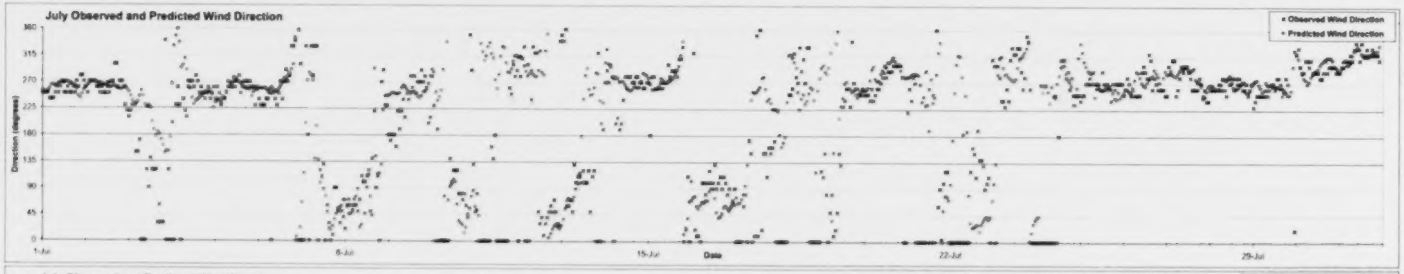


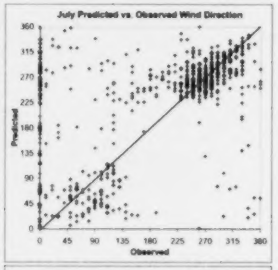


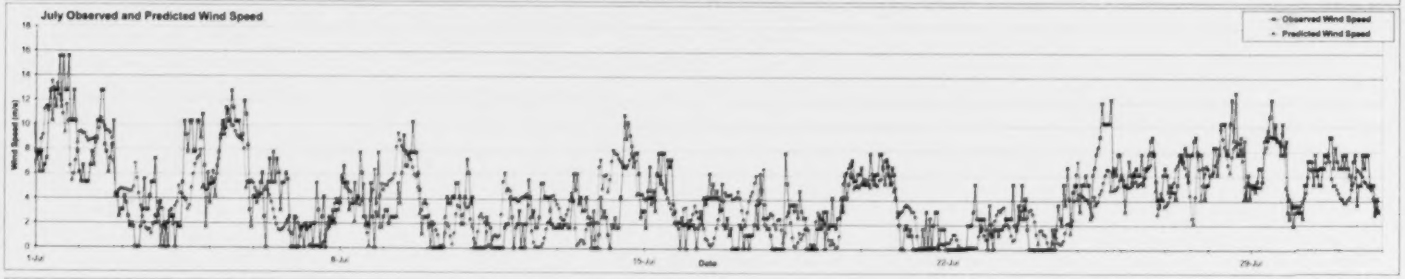


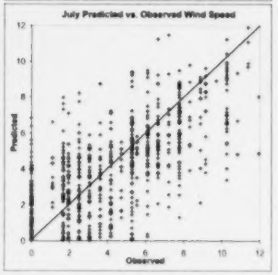


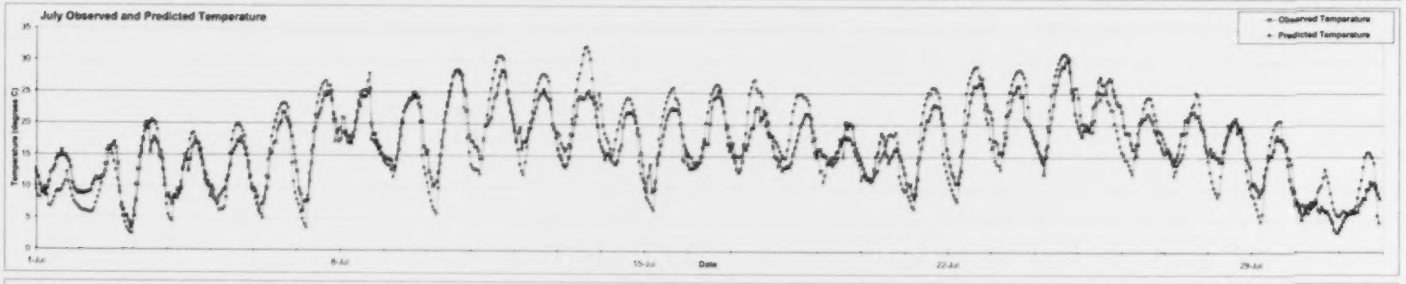
STATION: Grande Prairie 12km MM5

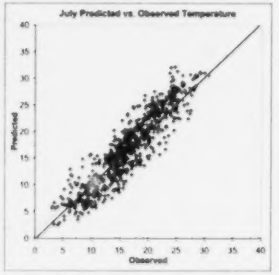


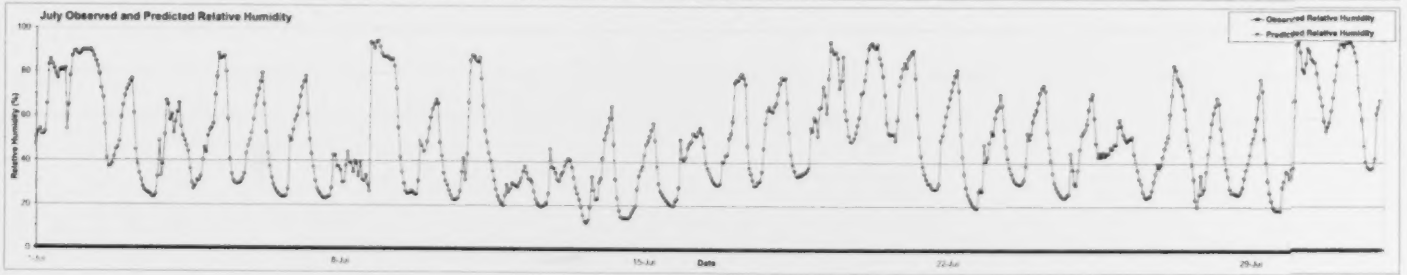




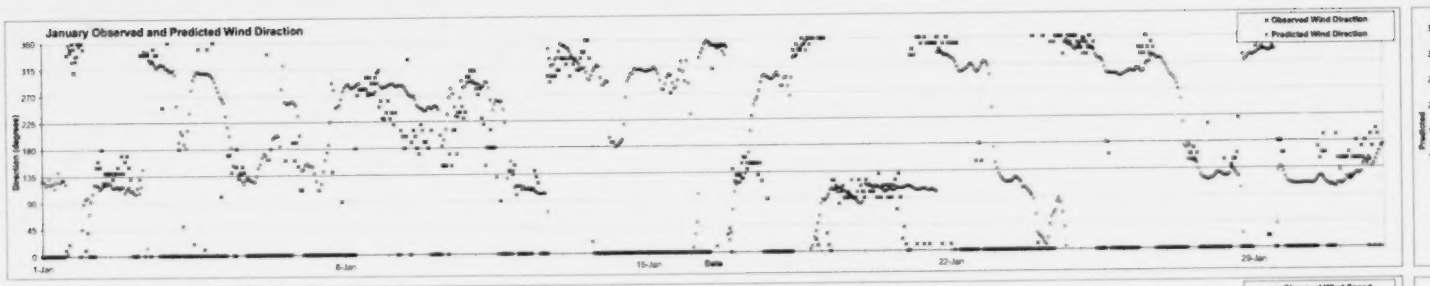


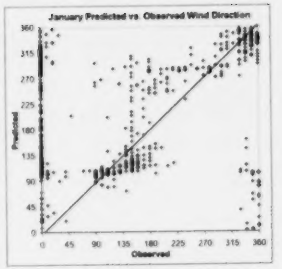


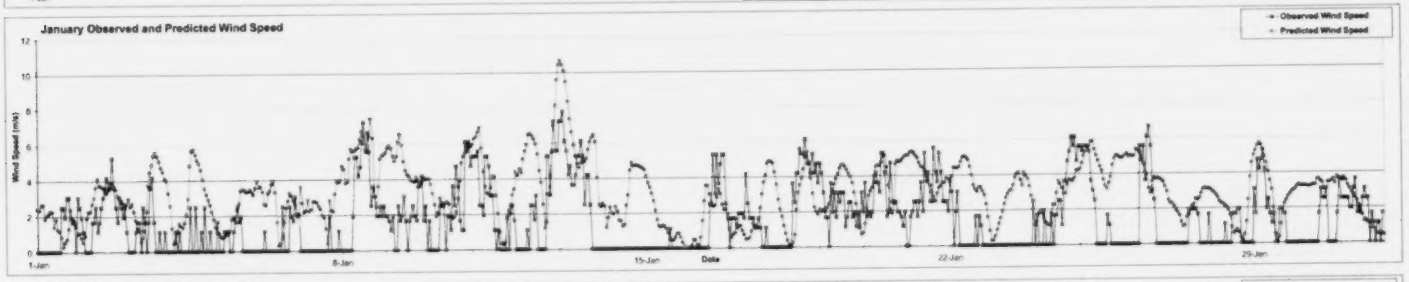


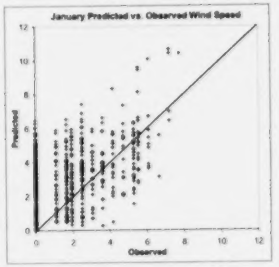


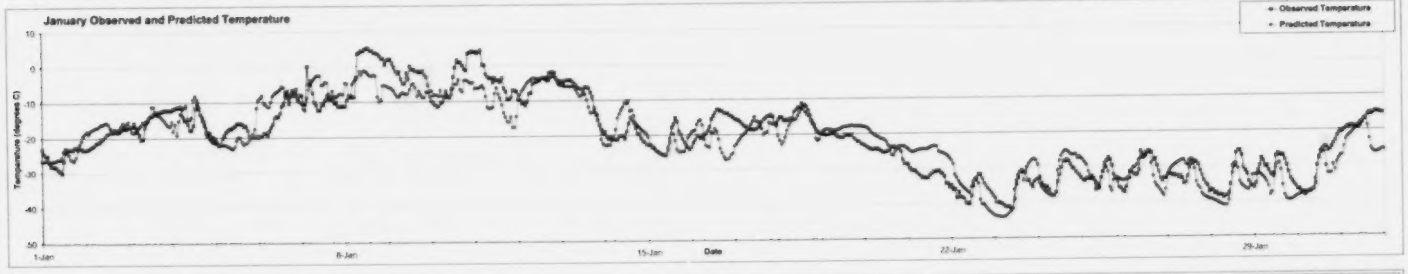
STATION: High Level 12km MM5

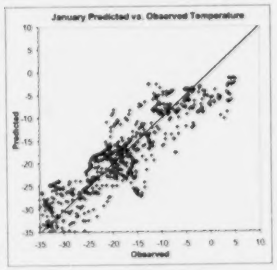


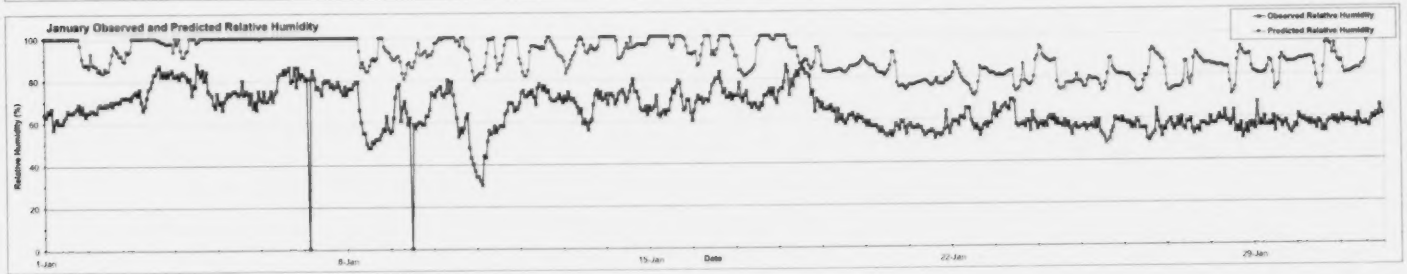


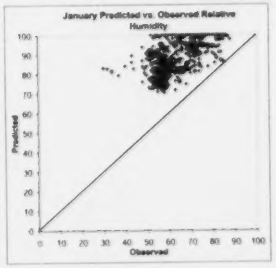




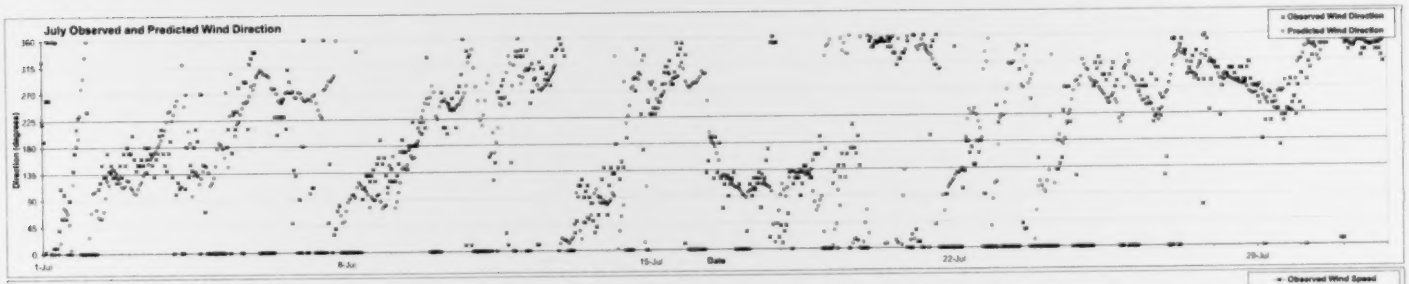


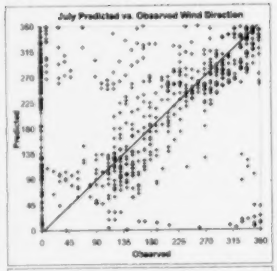


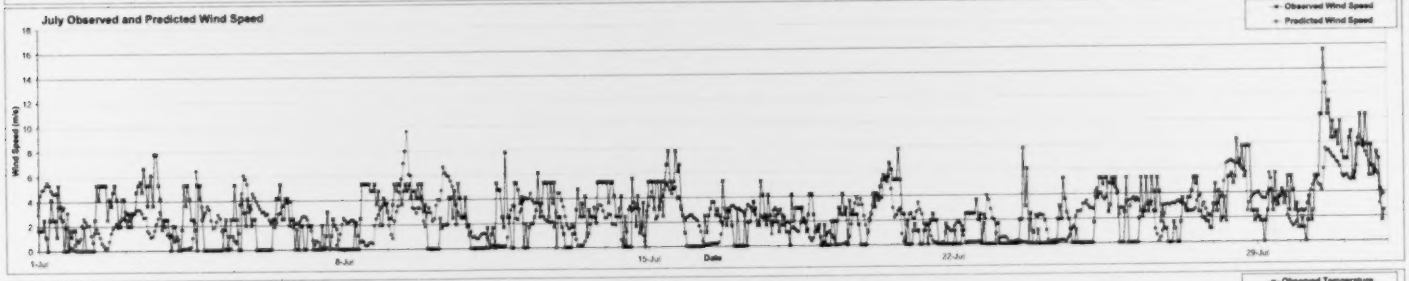


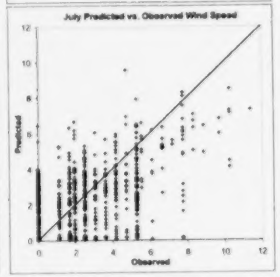


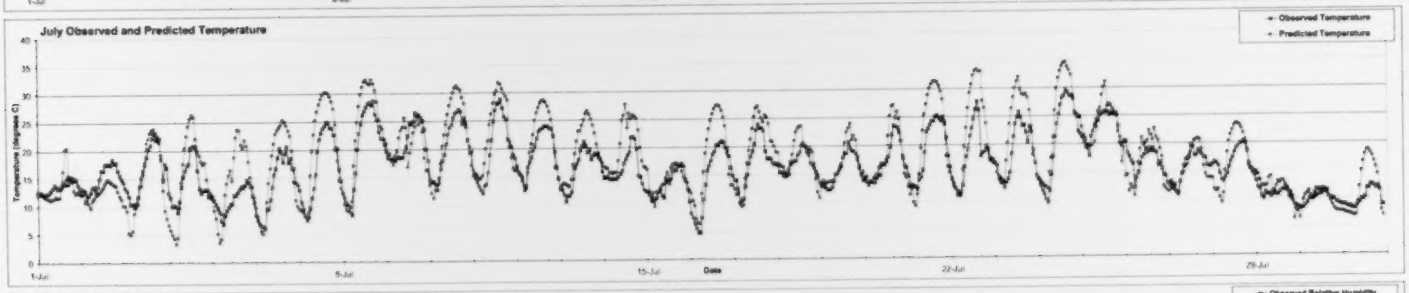
STATION: High Level 12km MM5

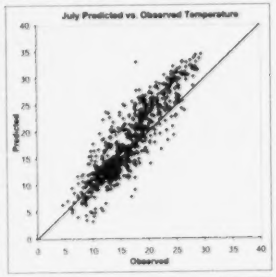


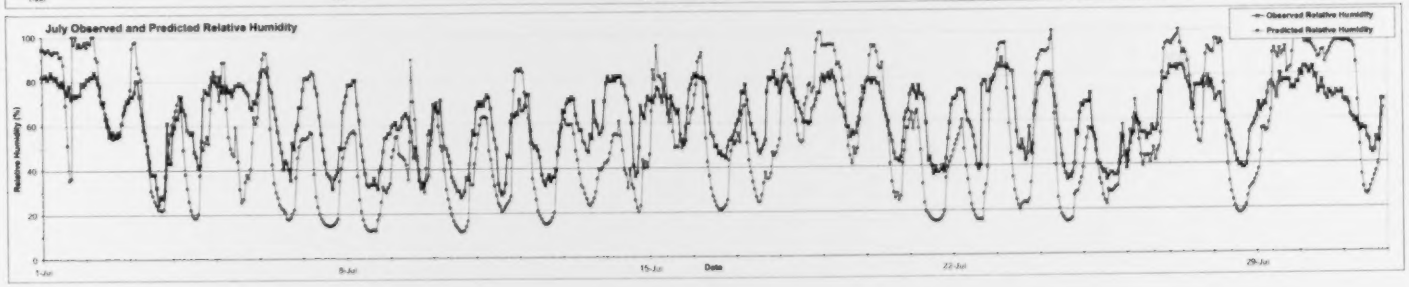


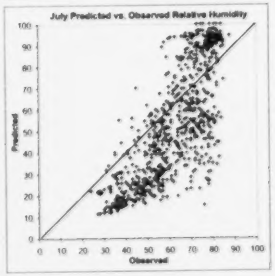




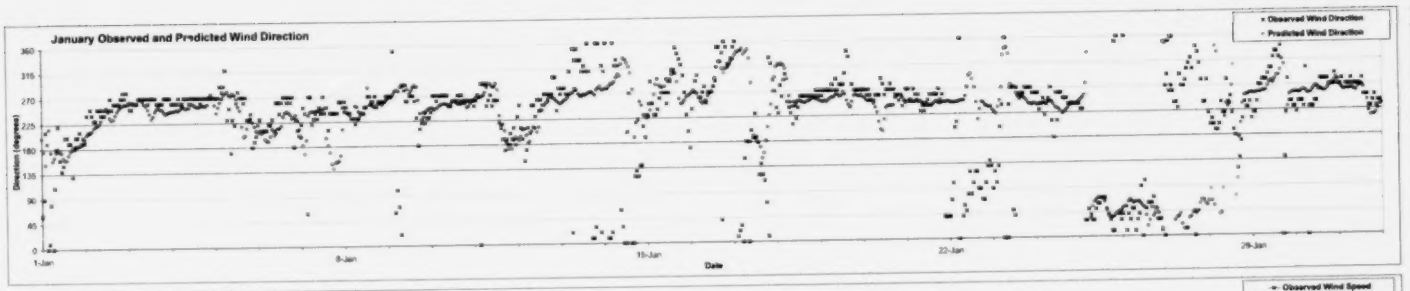


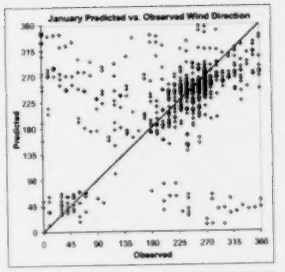


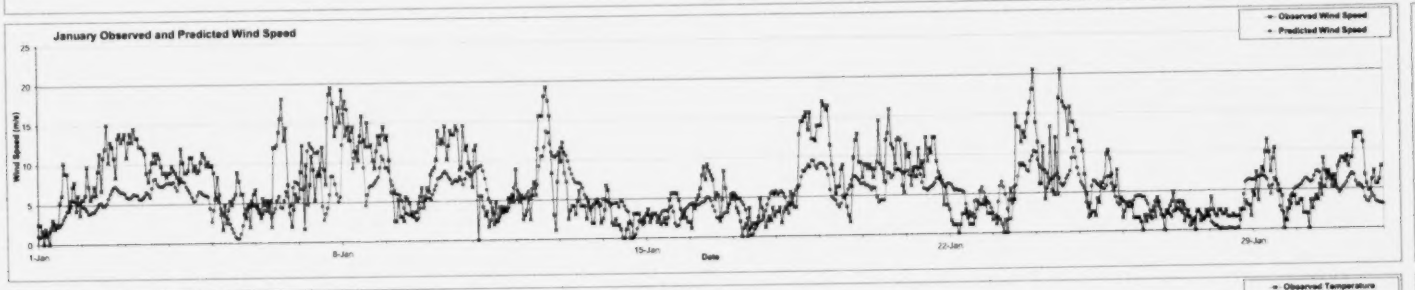


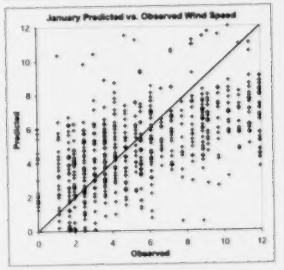


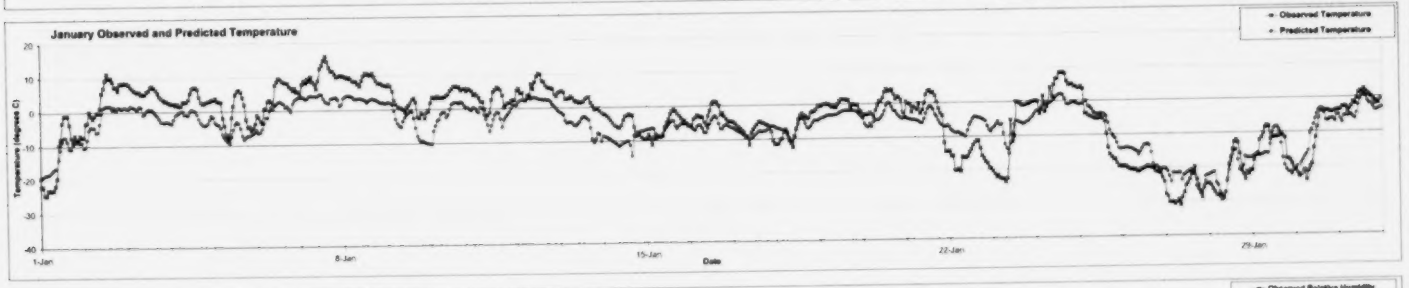
STATION: Lethbridge 12km MM5

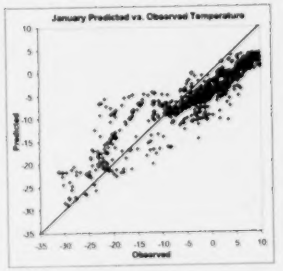


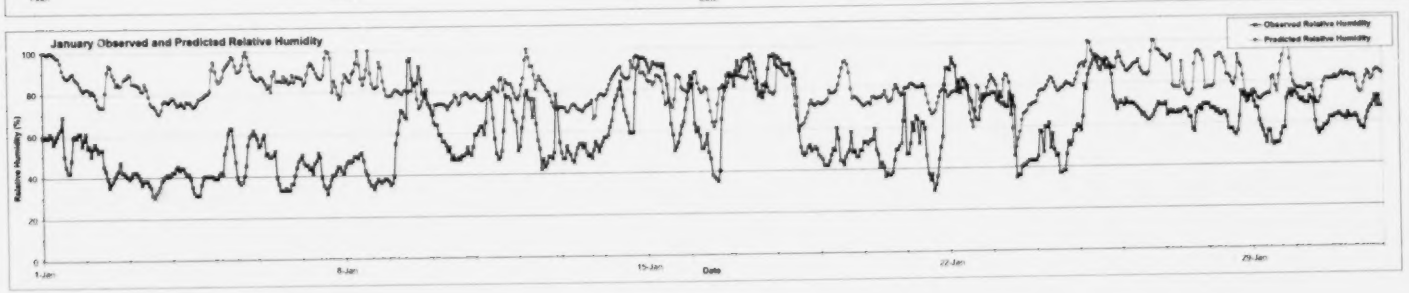


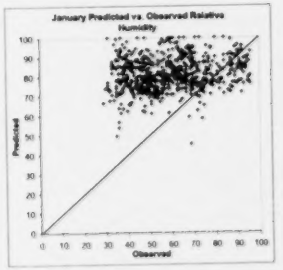




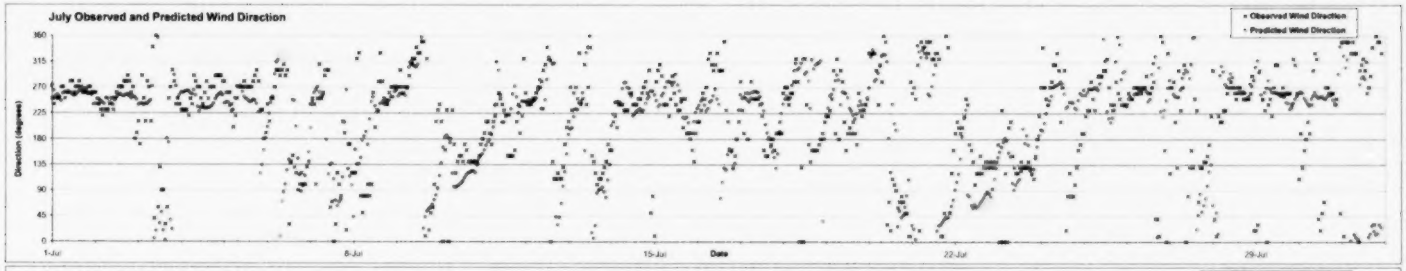


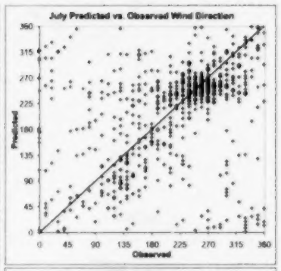


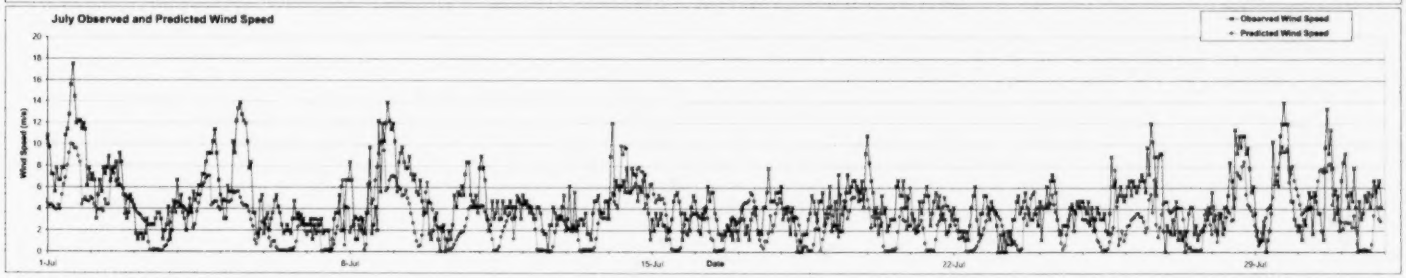


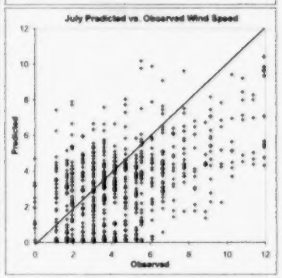


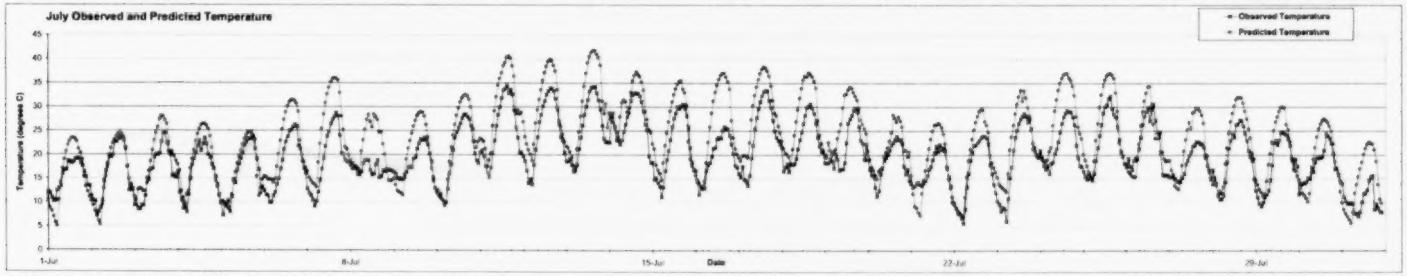
STATION: Lethbridge 12km MM5

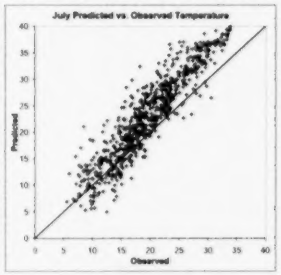


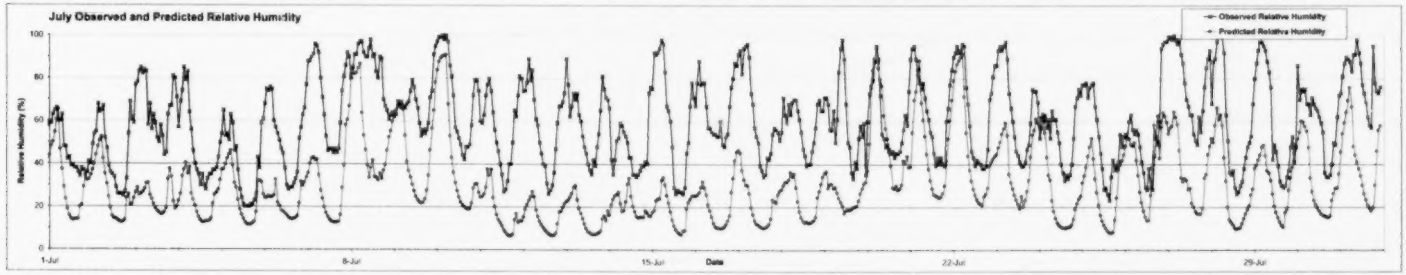


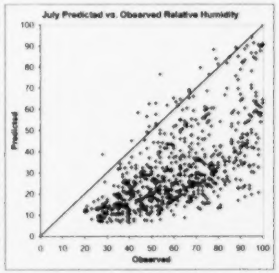




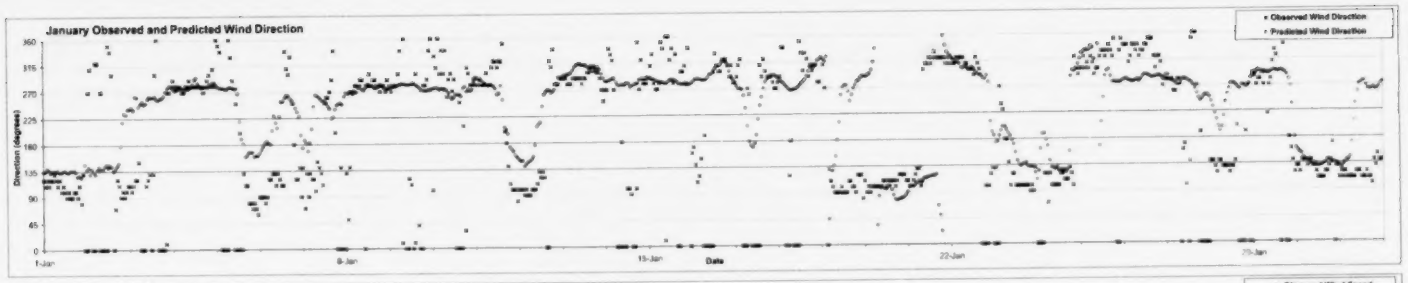


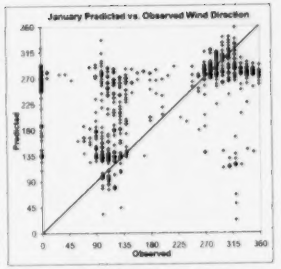


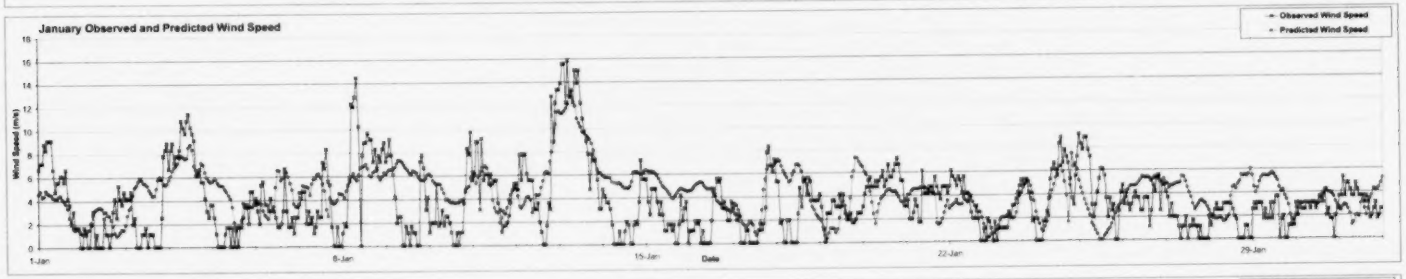


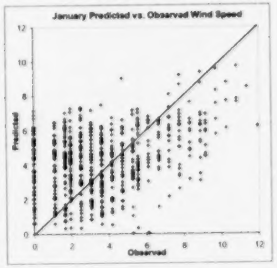


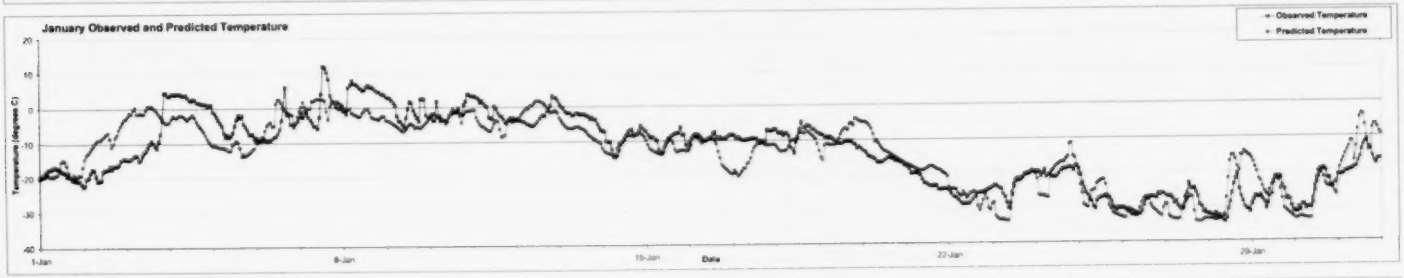
STATION: Slave Lake 12km MM5

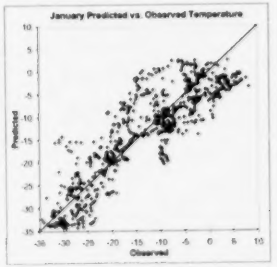


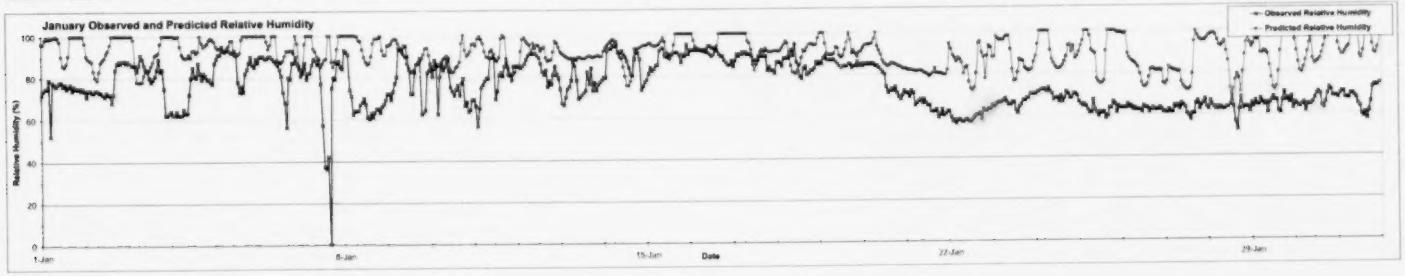


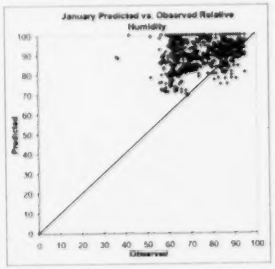




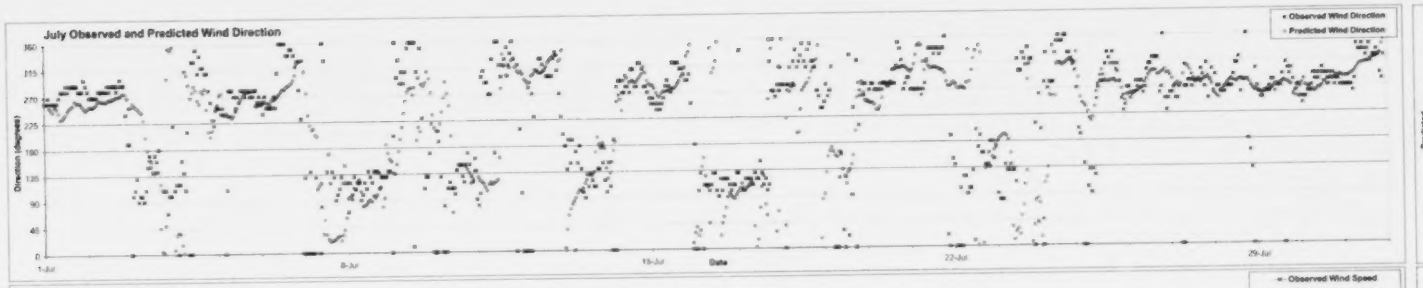


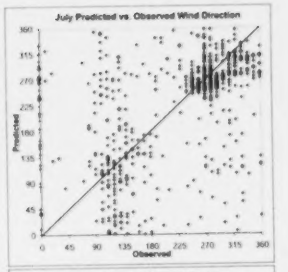


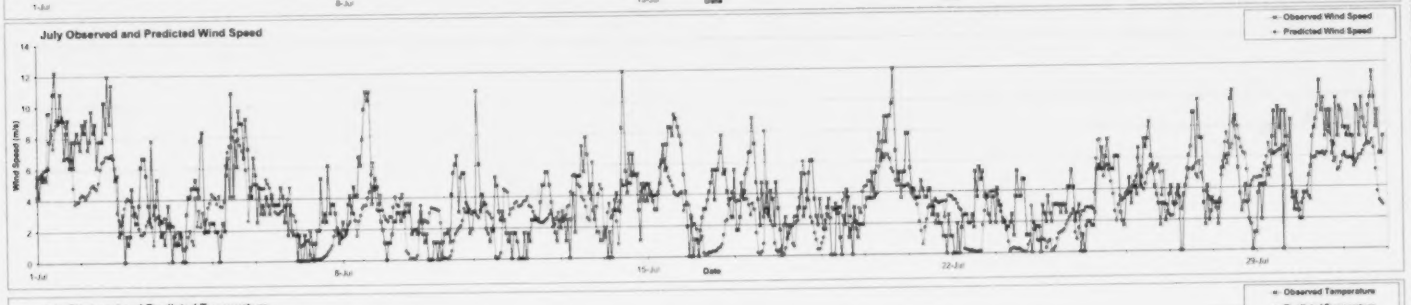


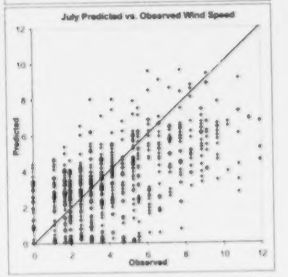


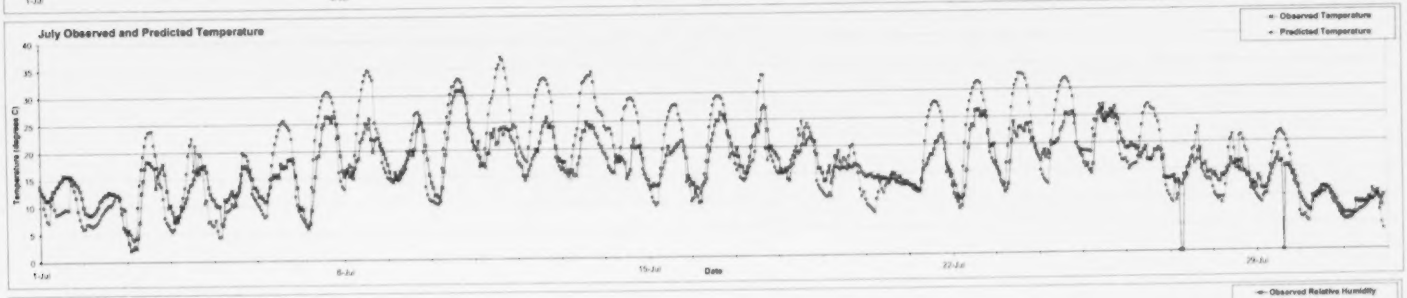
STATION: Slave Lake 12km MM5

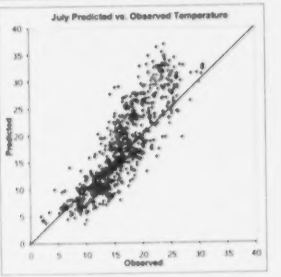


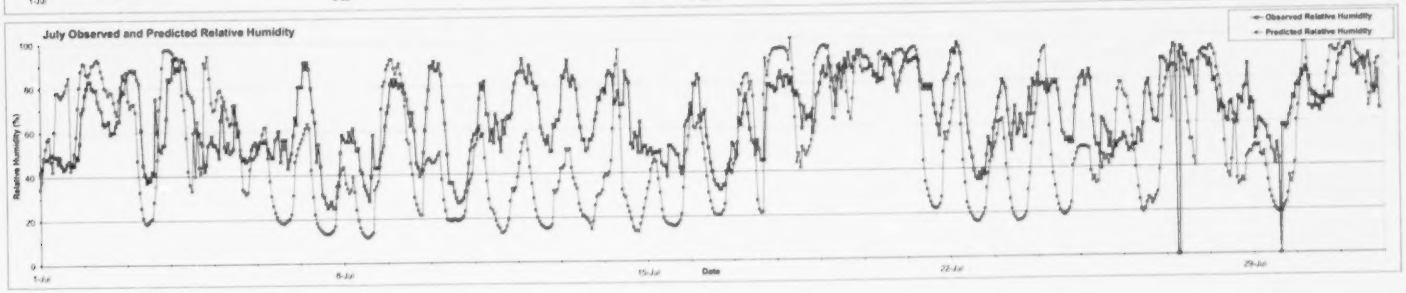


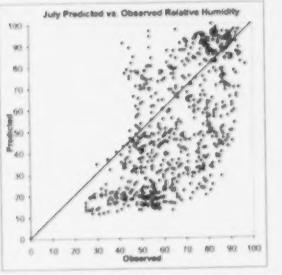






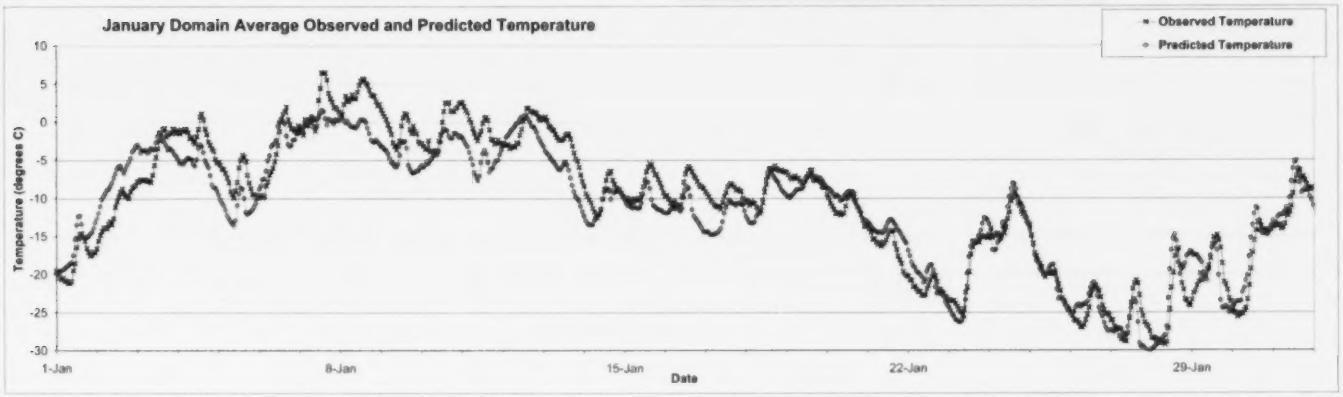


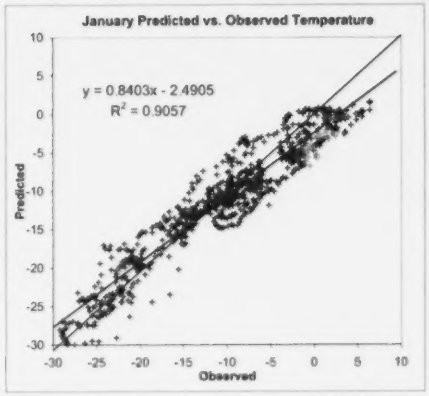


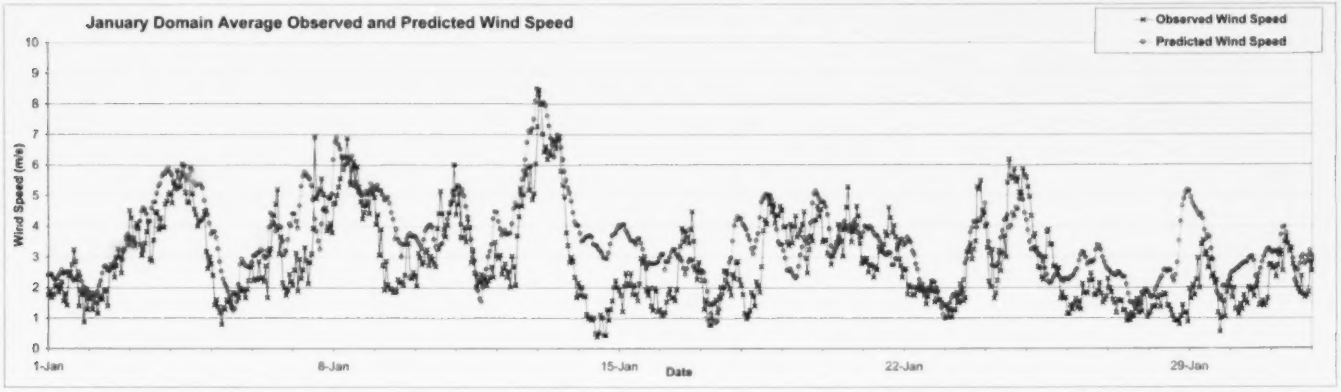


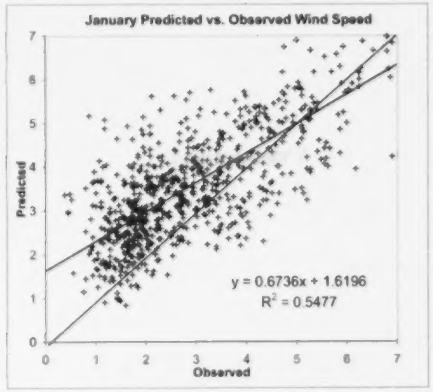
APPENDIX B

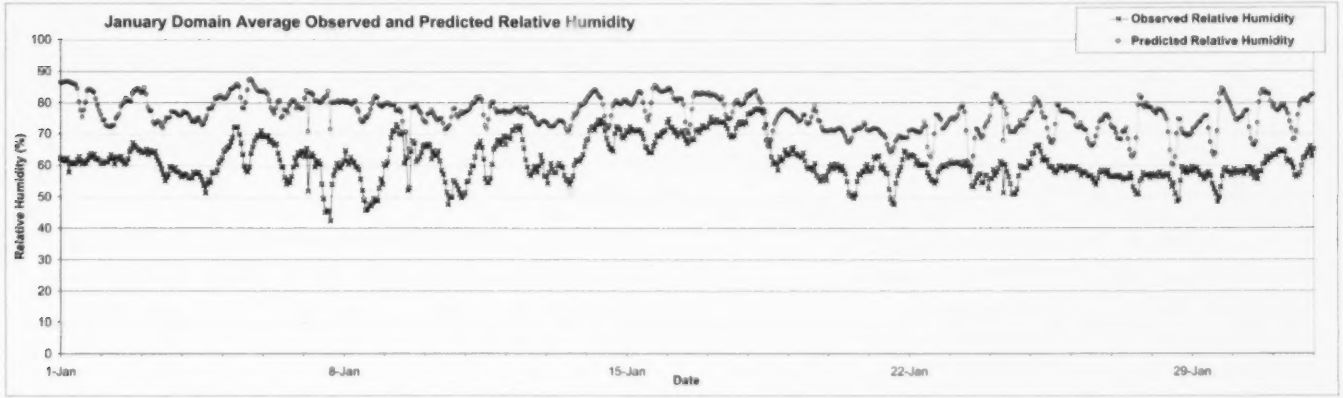
STATISTICS: Domain Wide 12km MM5

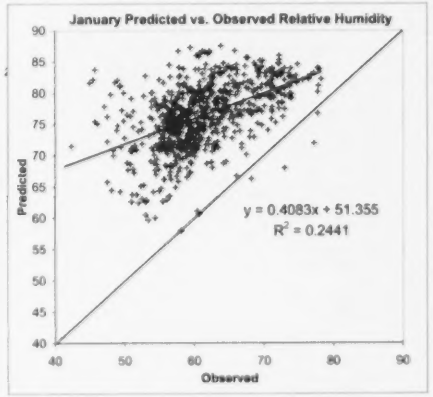




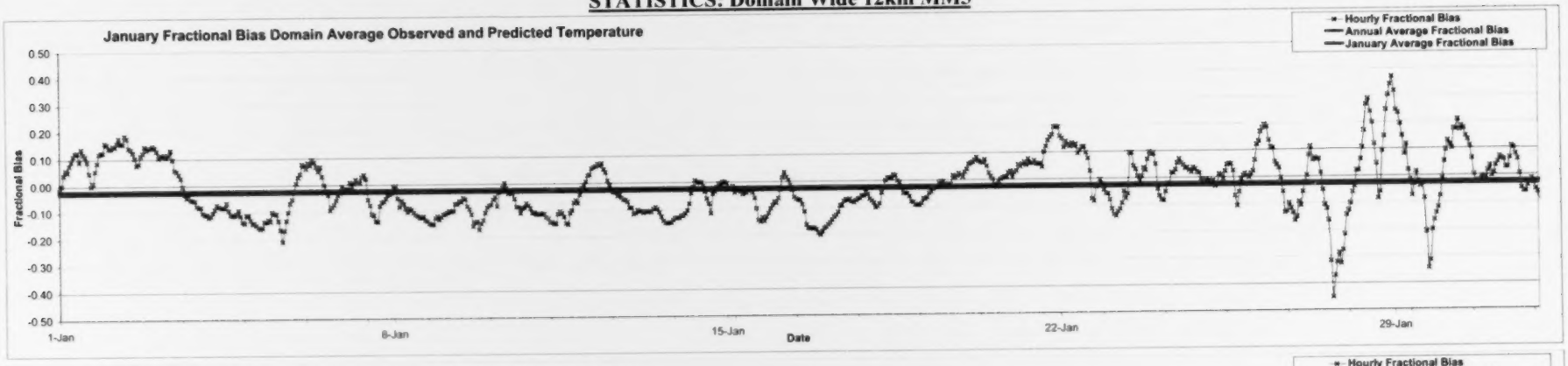


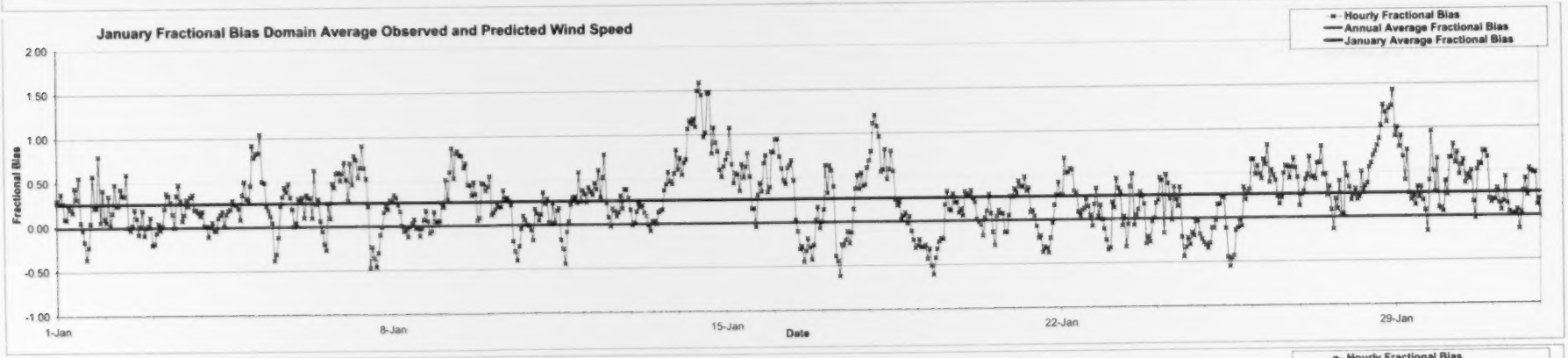


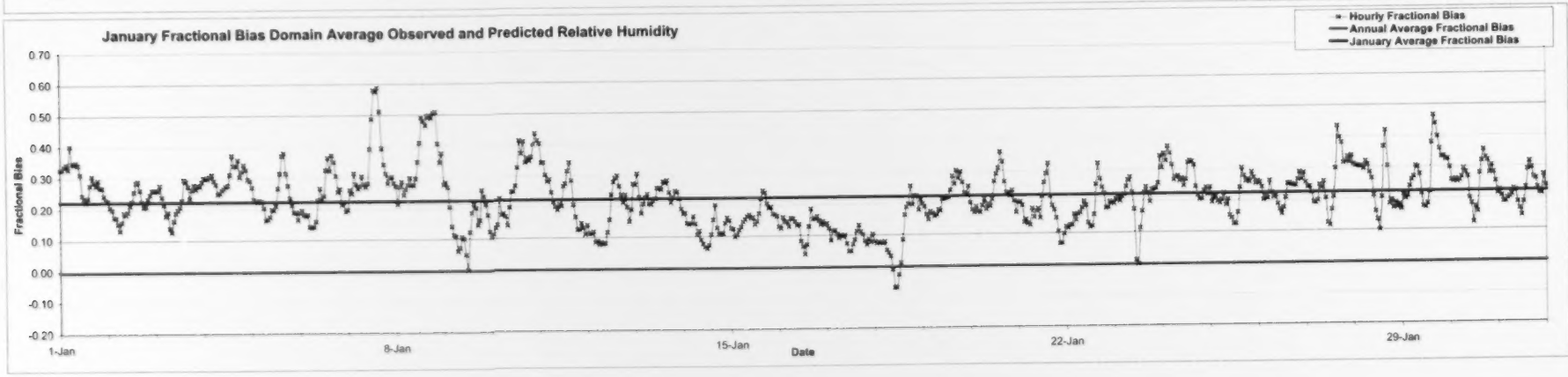




STATISTICS: Domain Wide 12km MM5







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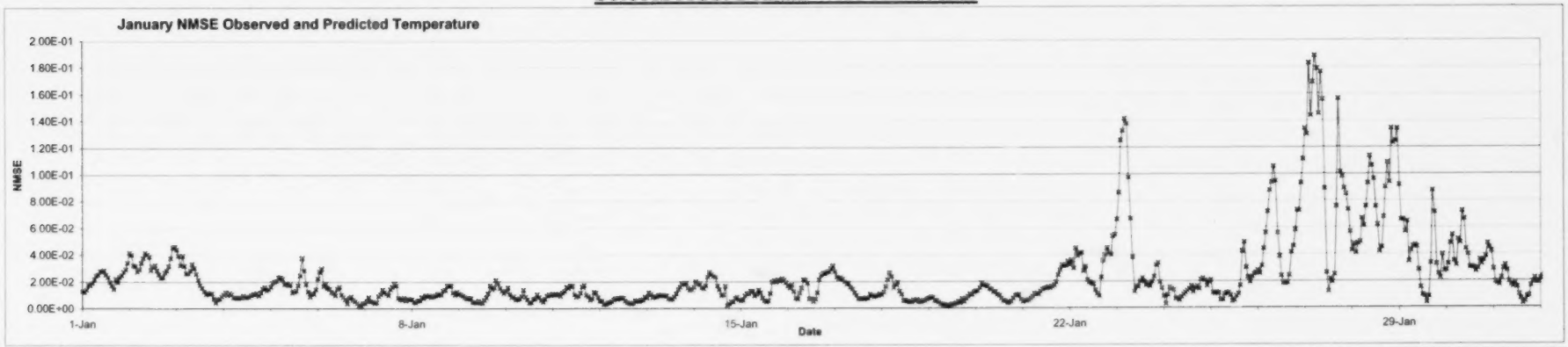
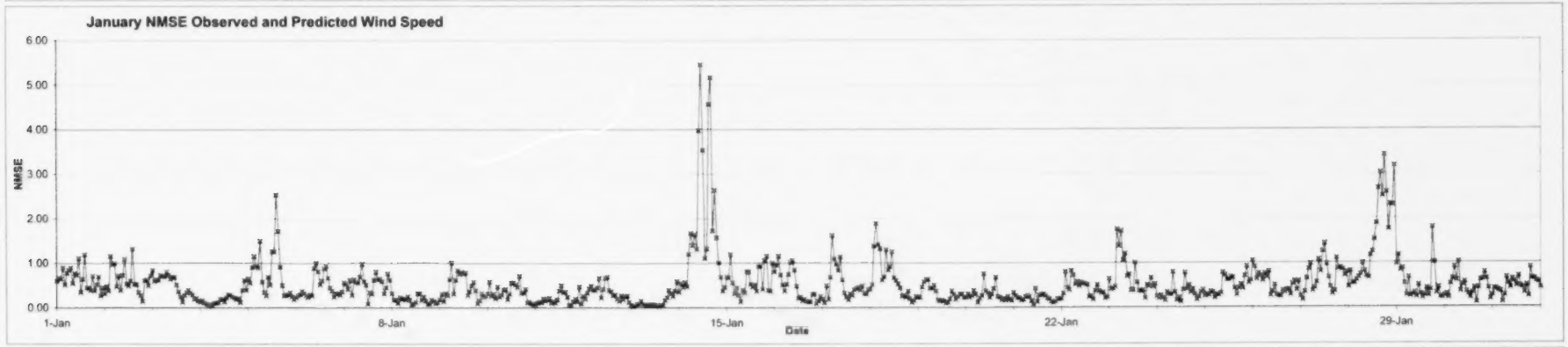
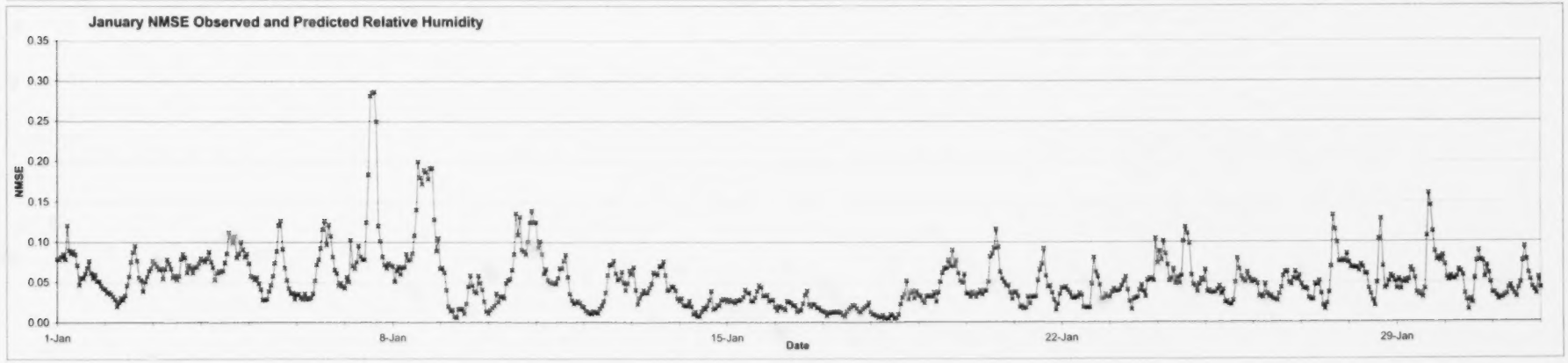
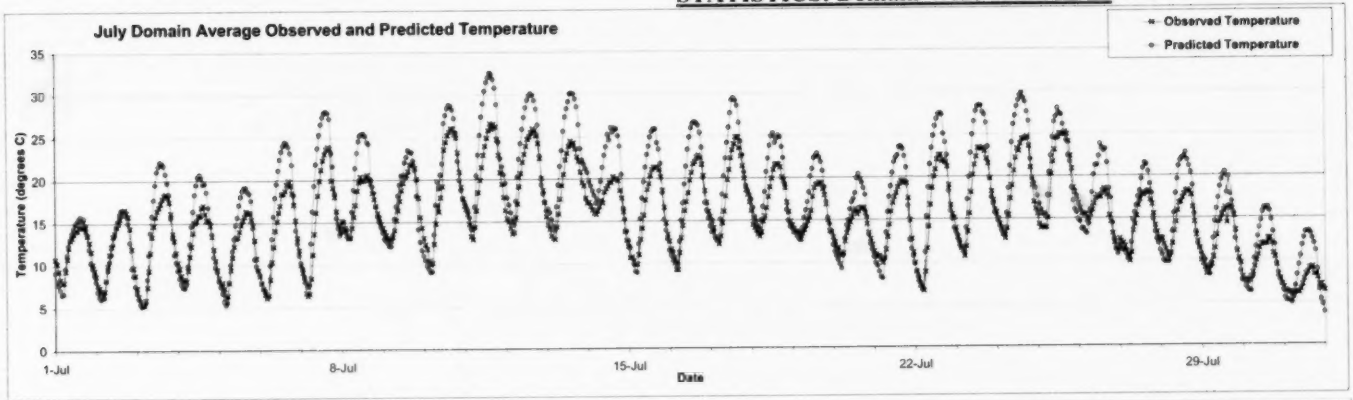
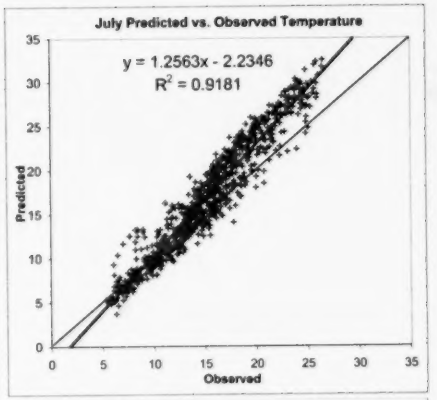


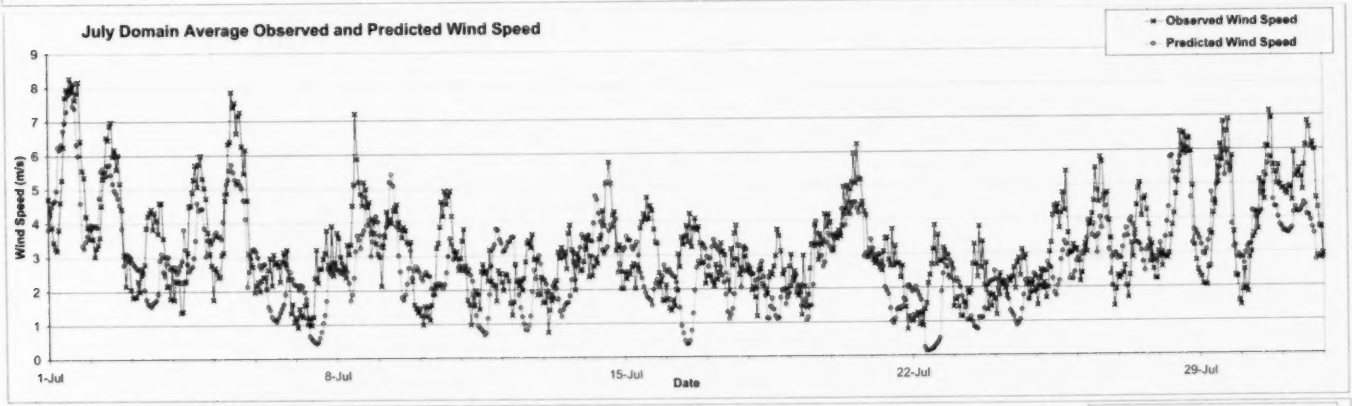


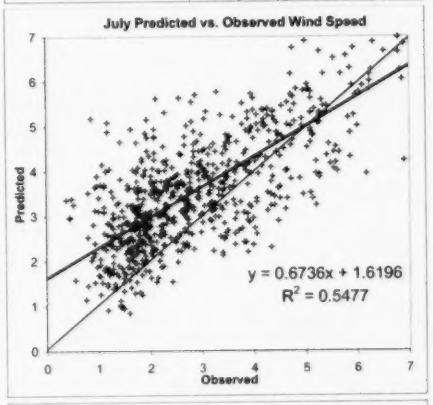


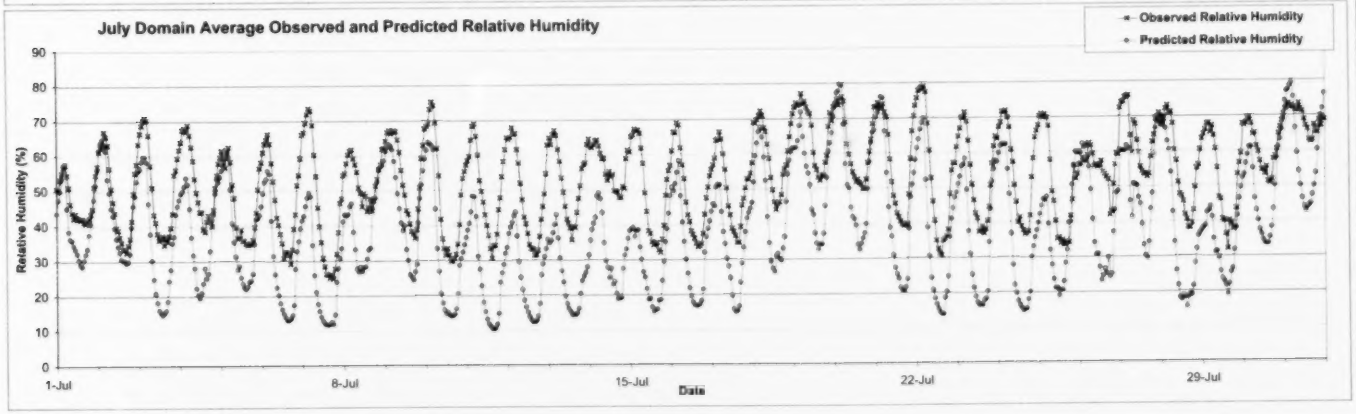
STATISTICS: Domain Wide 12km MM5

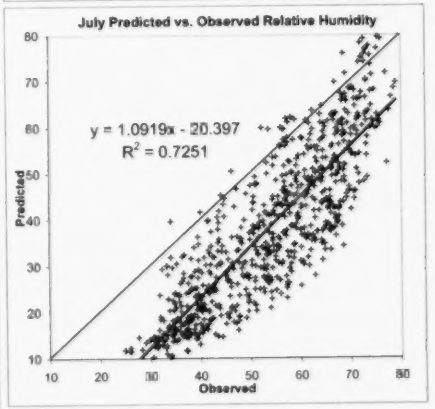




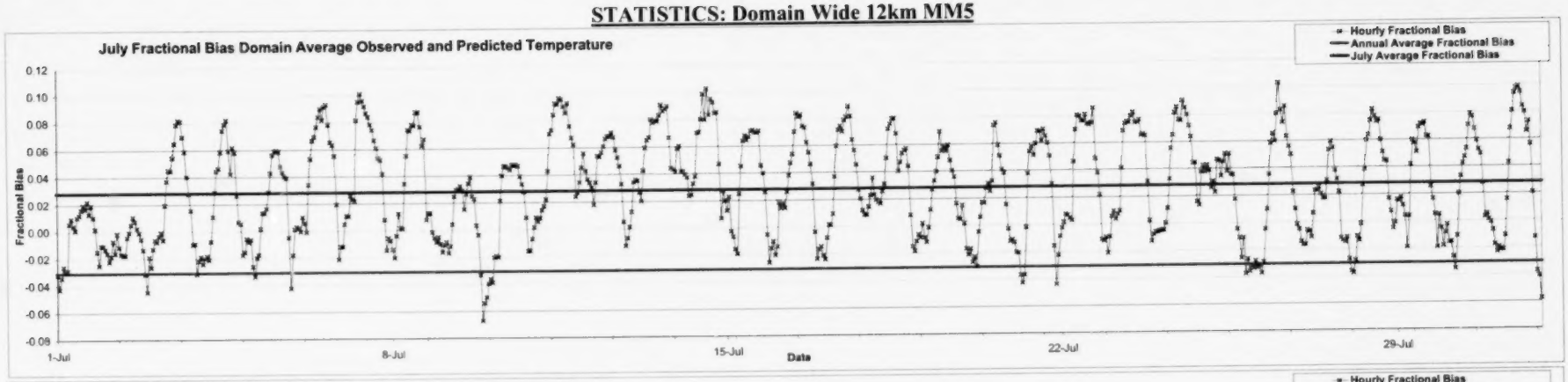


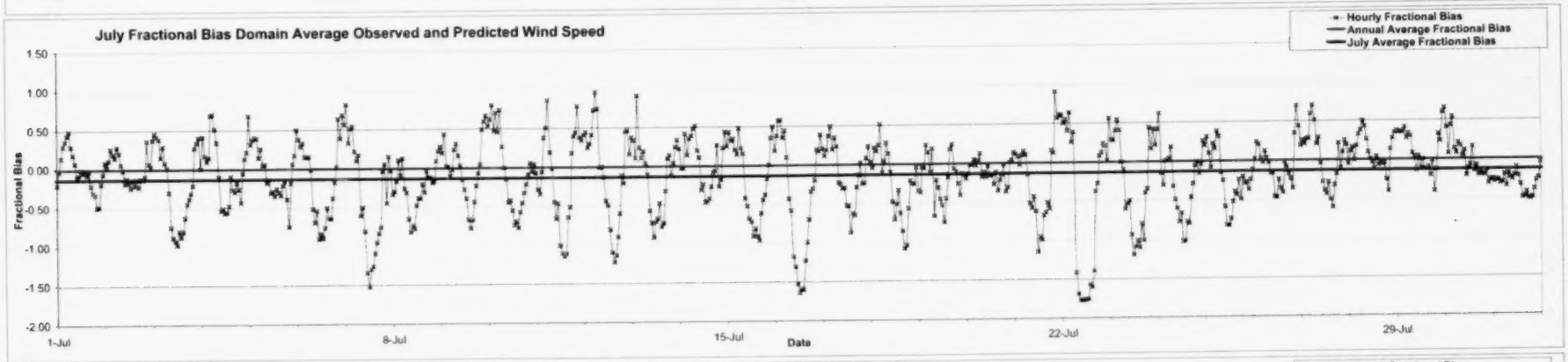


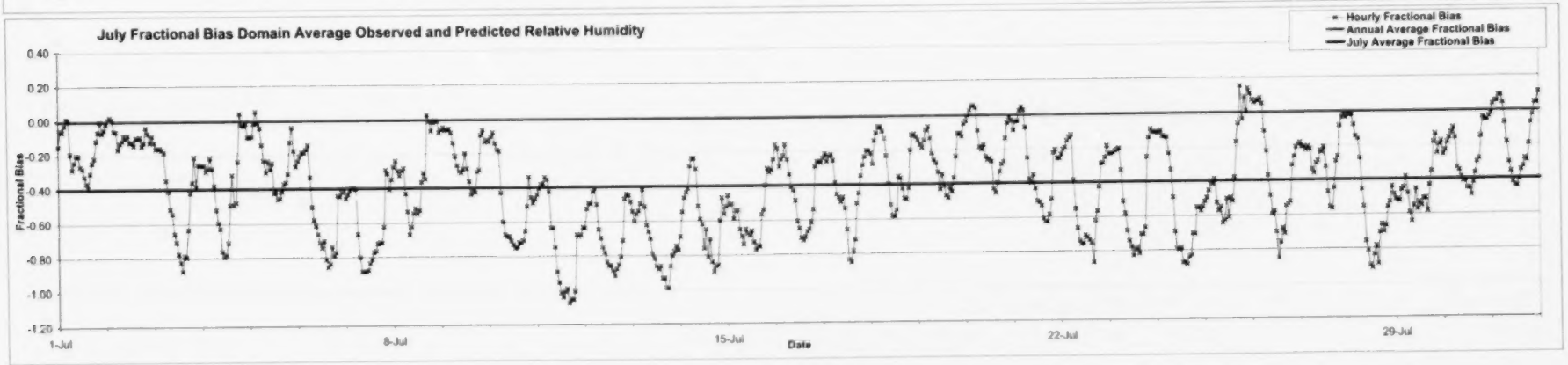




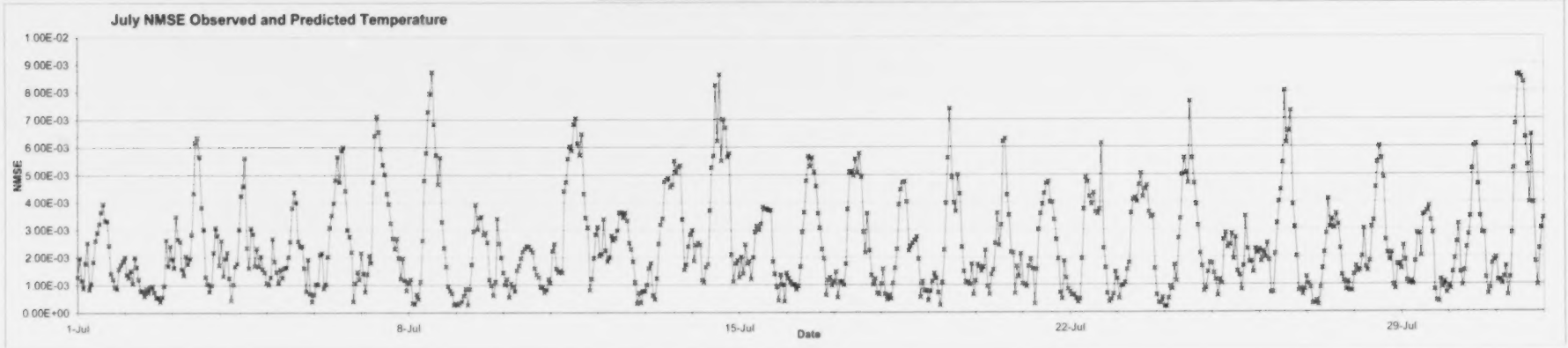
STATISTICS: Domain Wide 12km MM5

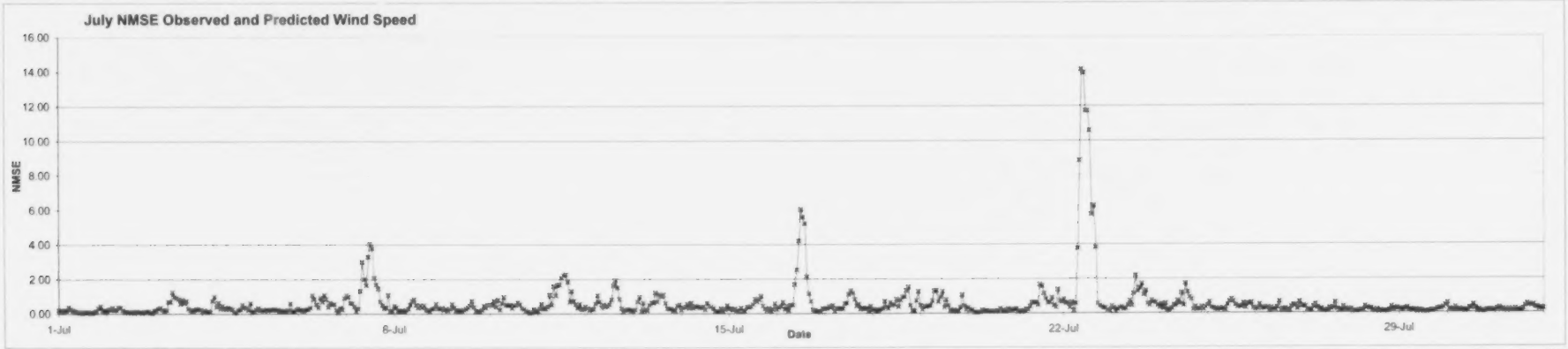


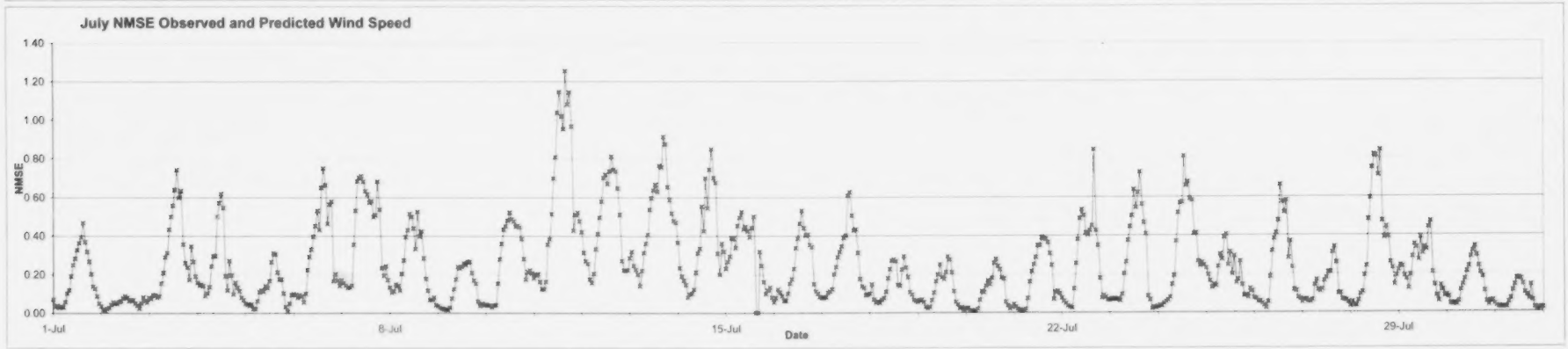




STATISTICS: Domain Wide 12km MM5

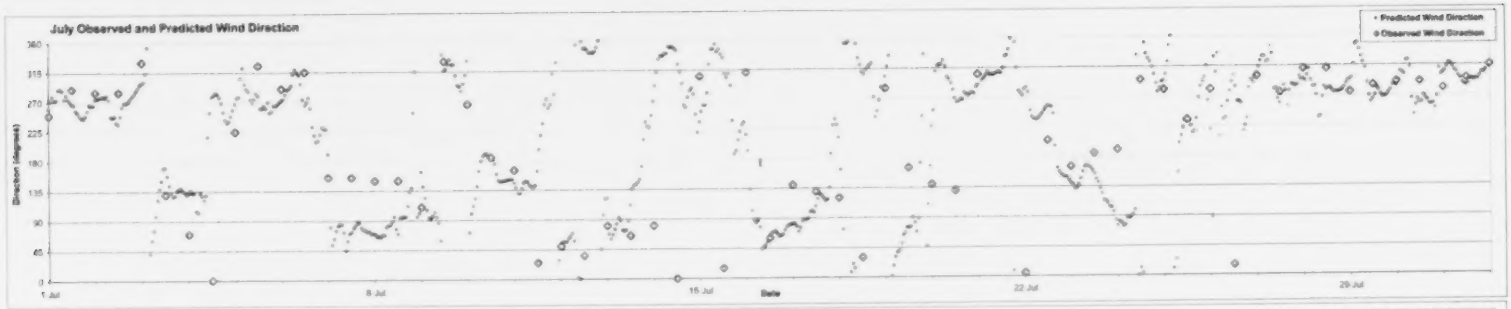


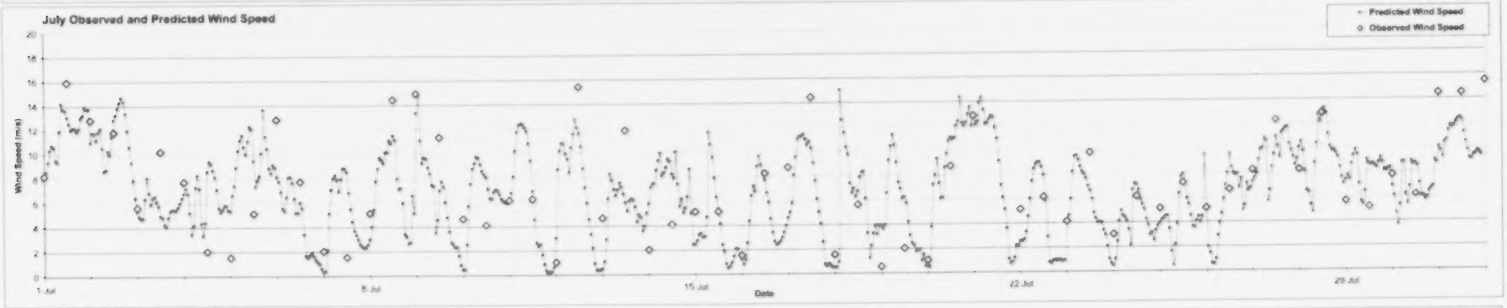


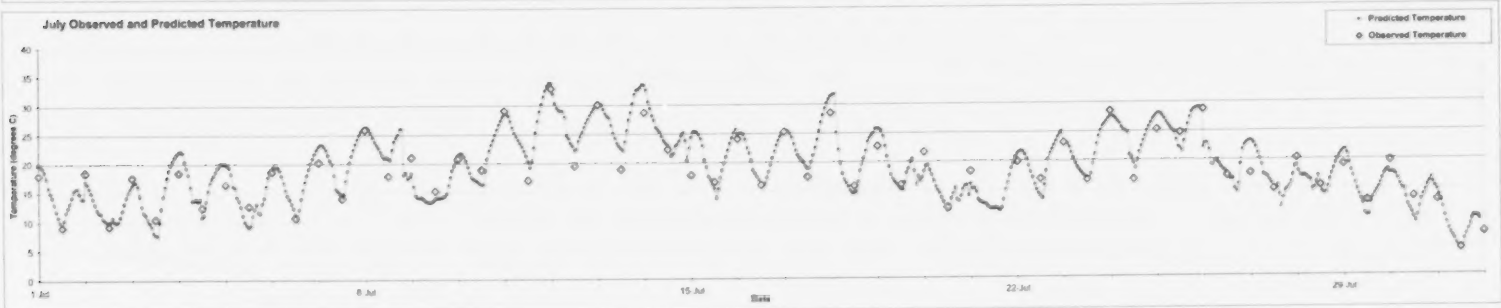


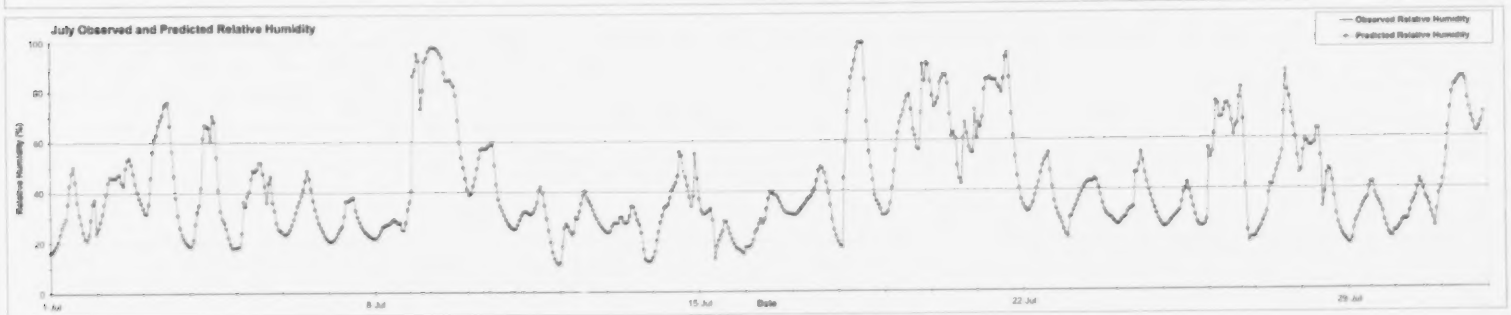
APPENDIX C

STATION: Stony Plain 100m MM5

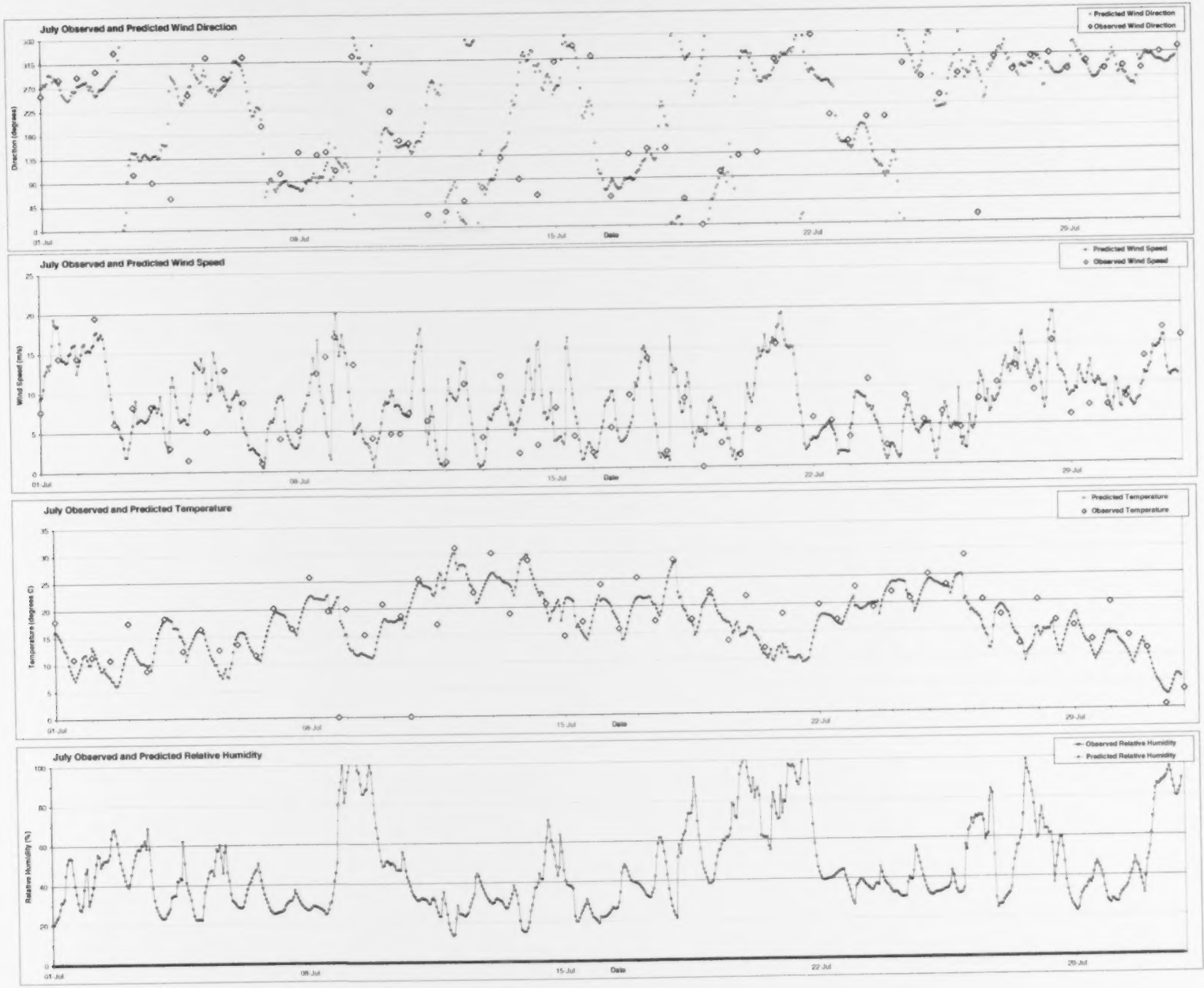




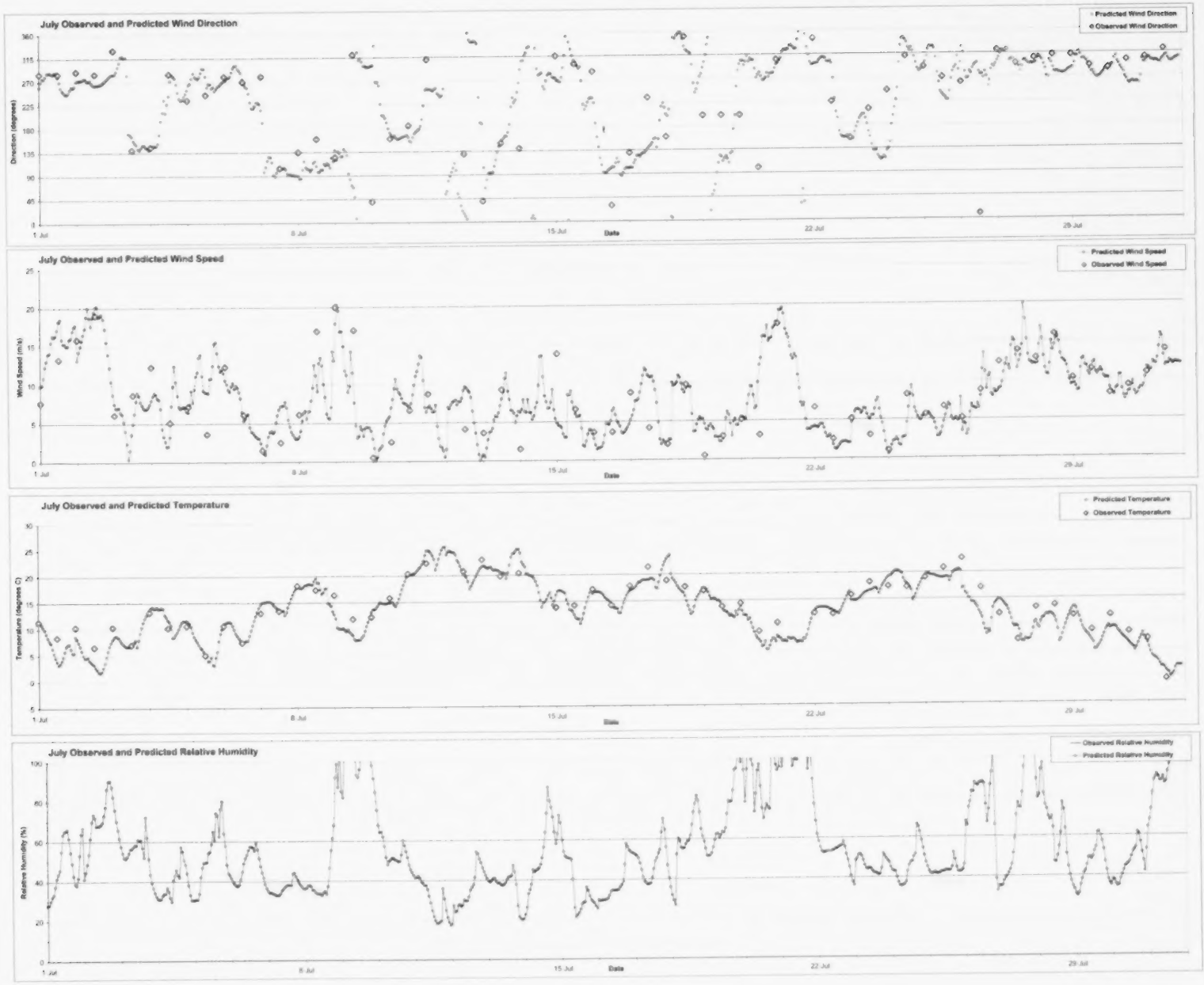




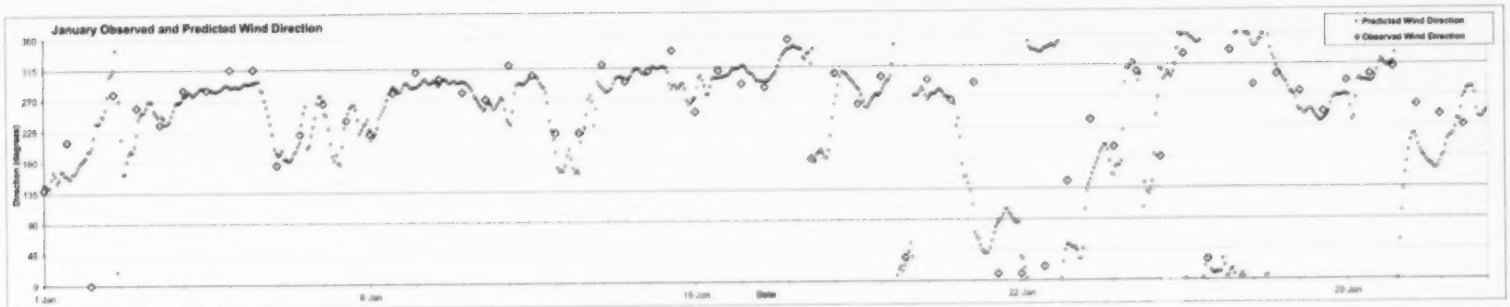
STATION: Stony Plain 500m MM5

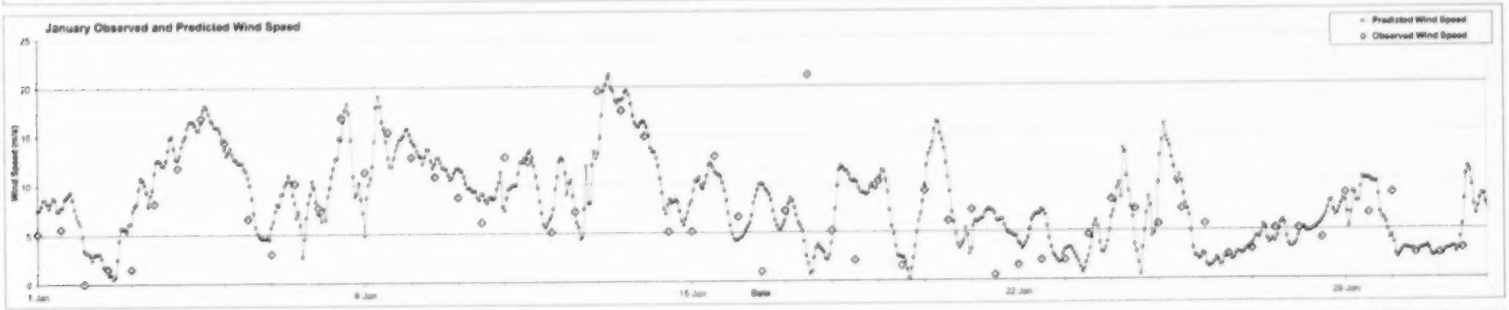


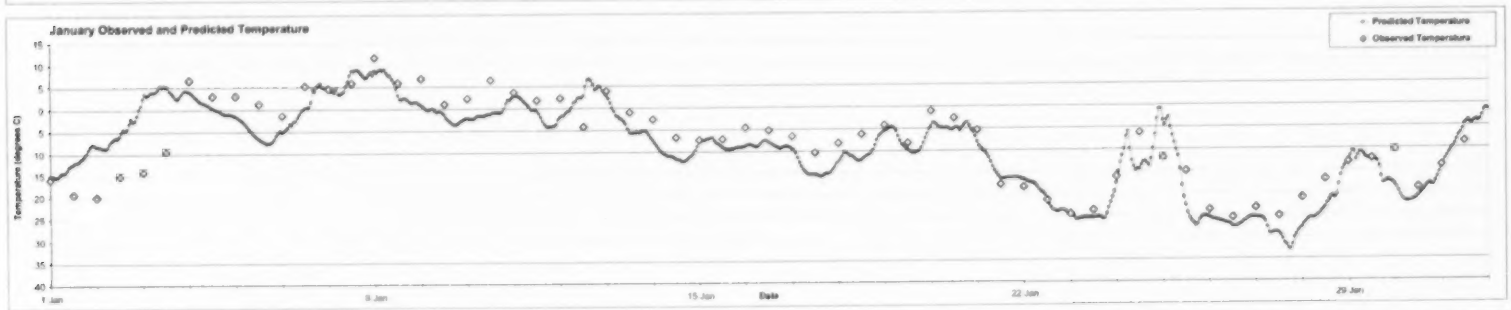
STATION: Stony Plain 1000m MM5

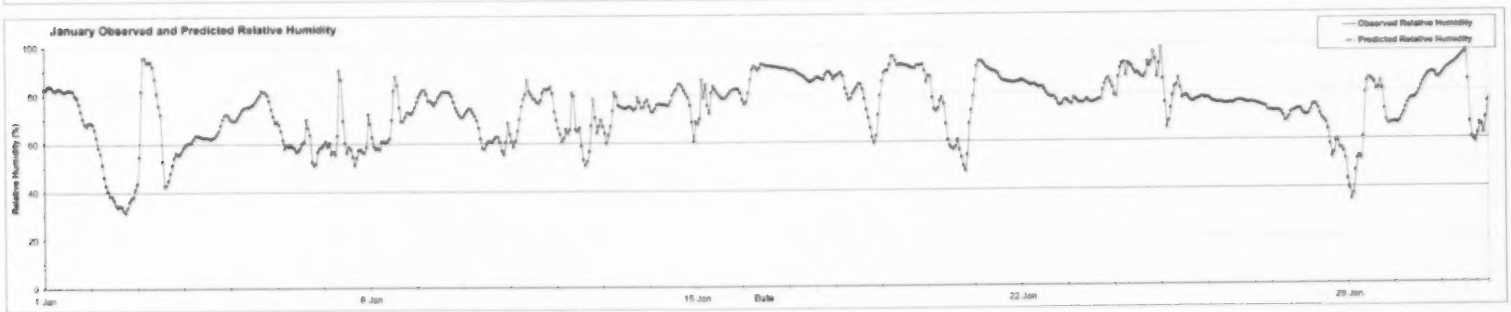


STATION: Stony Plain 100m MM5

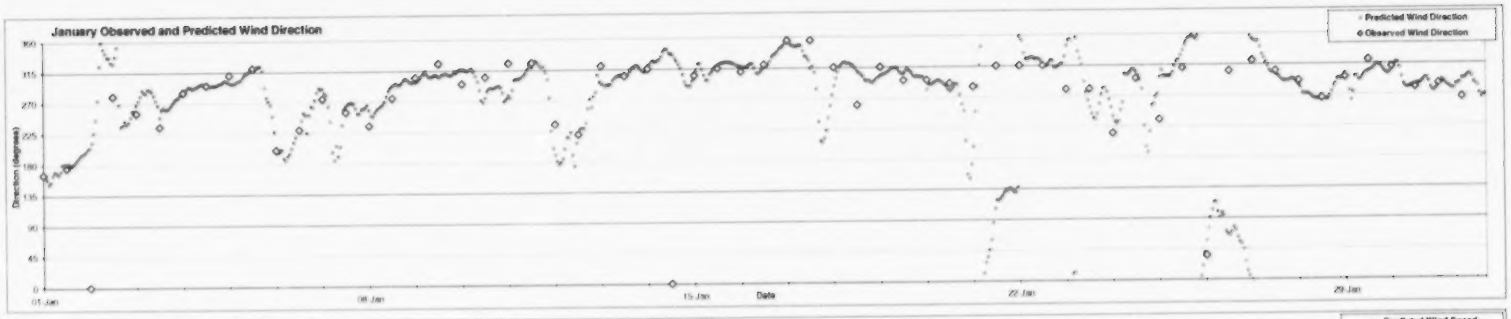


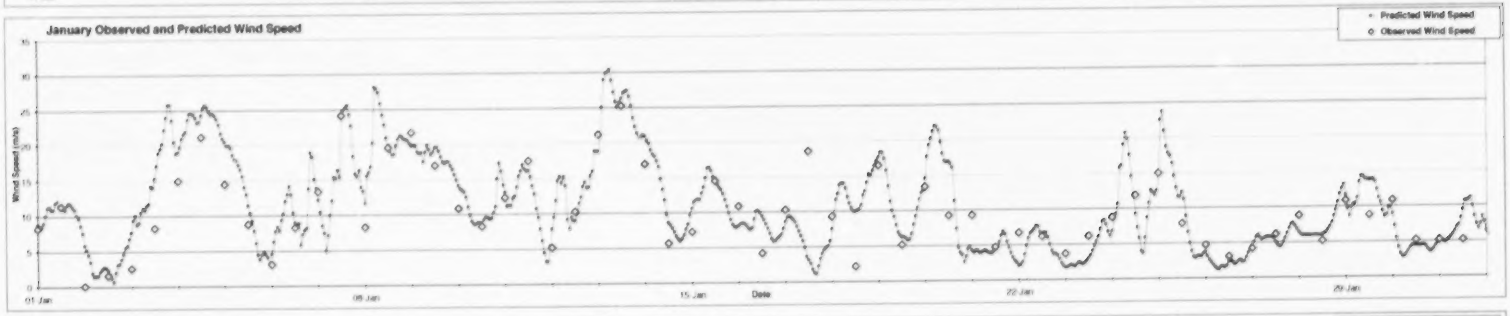


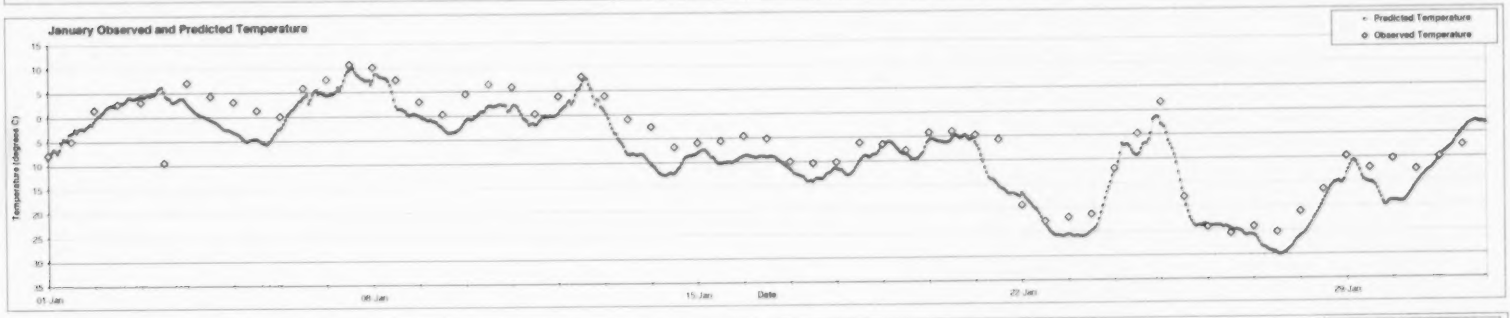


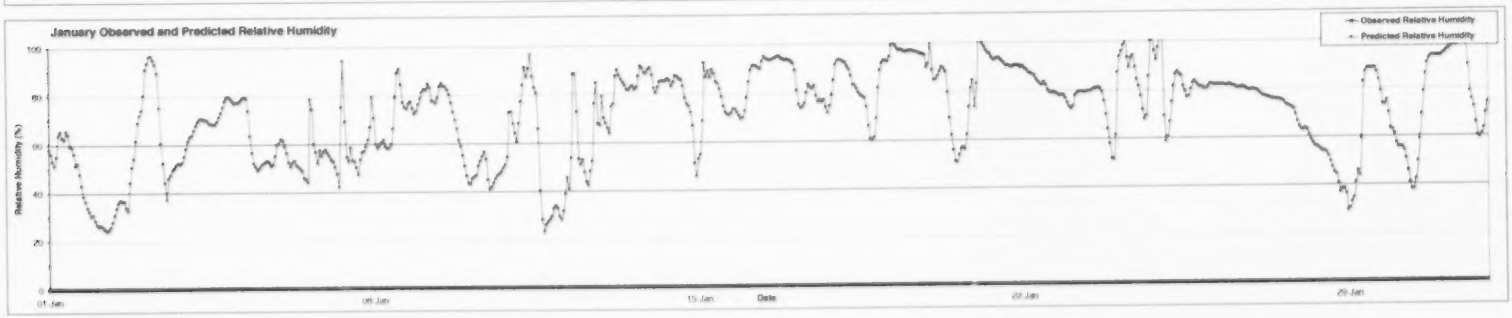


STATION: Stony Plain 500m MM5

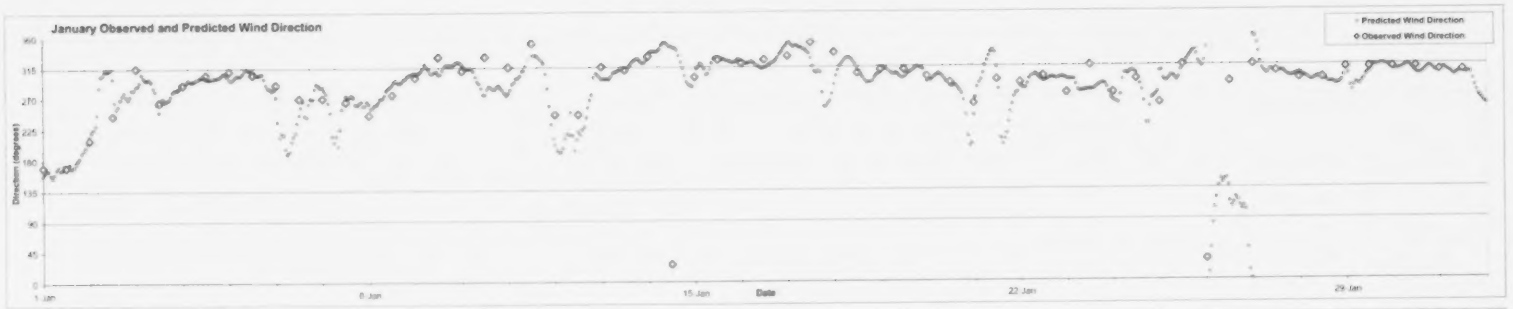


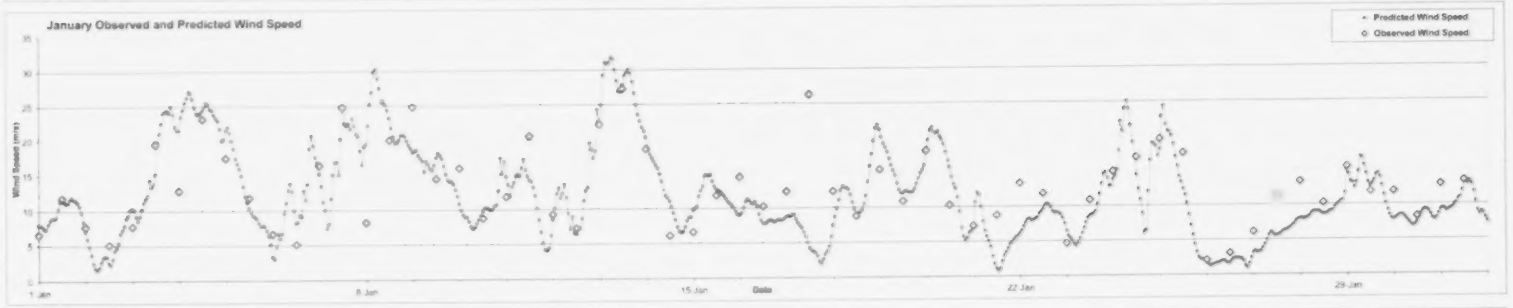


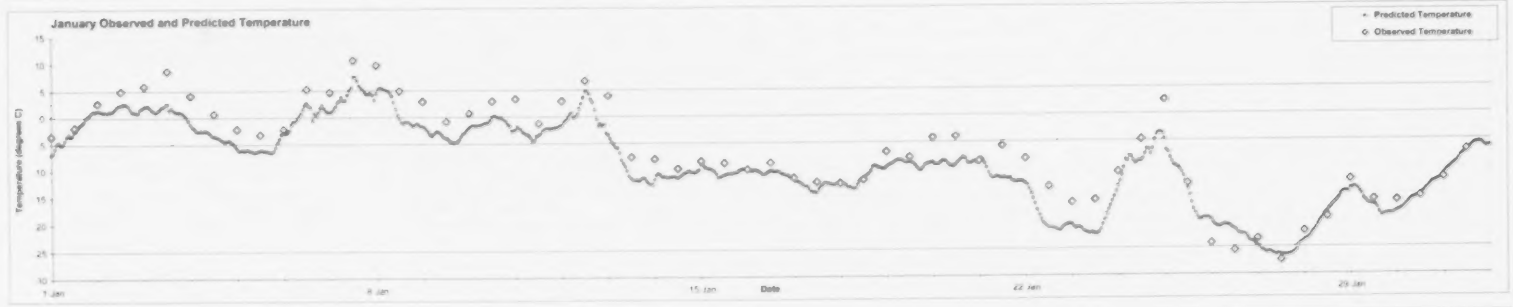


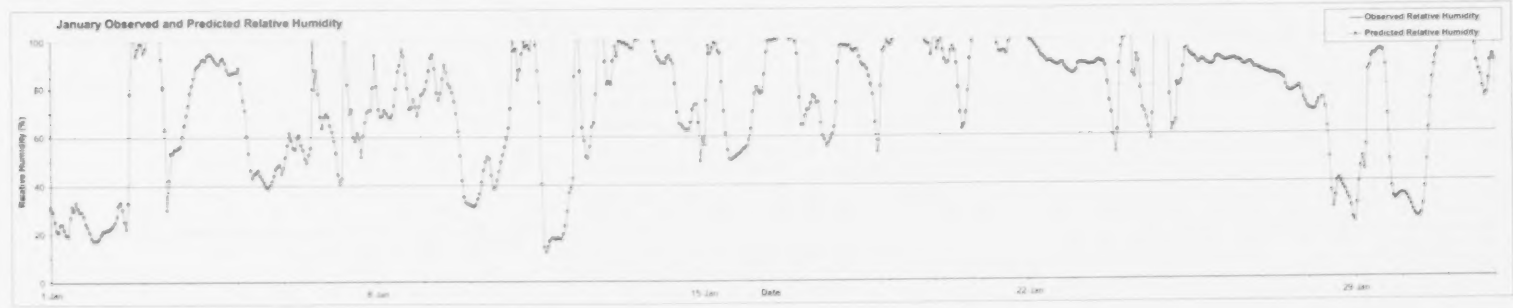


STATION: Stony Plain 1000m MM5

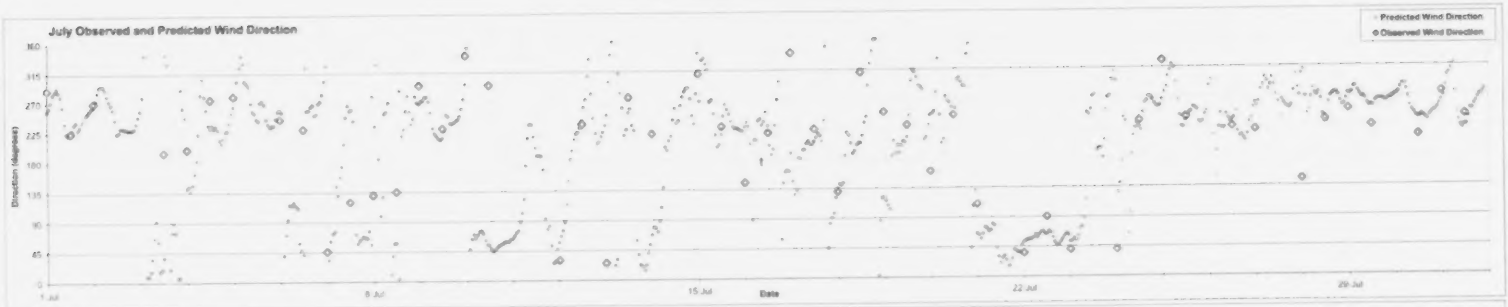


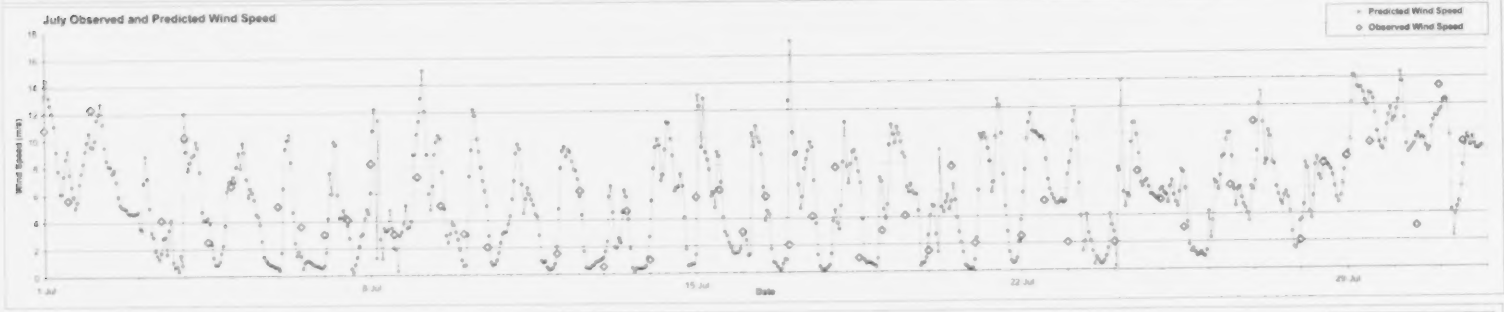


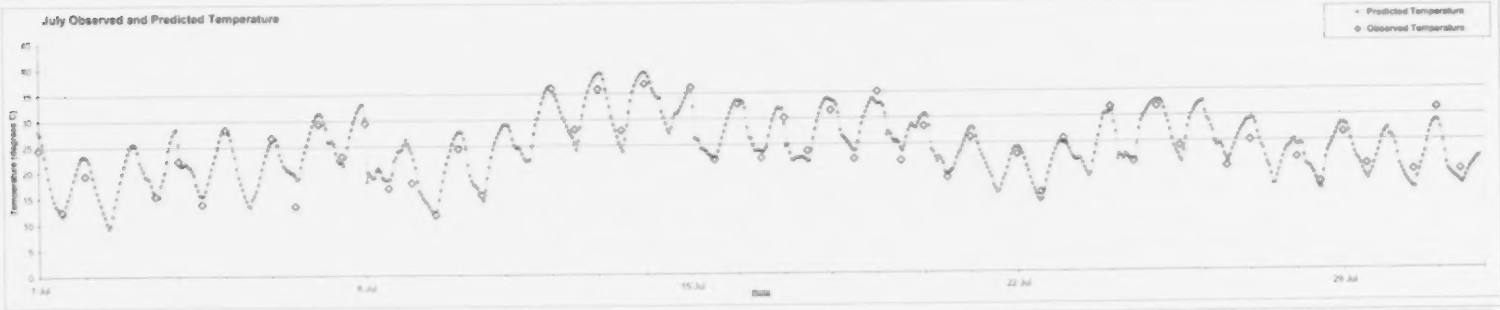


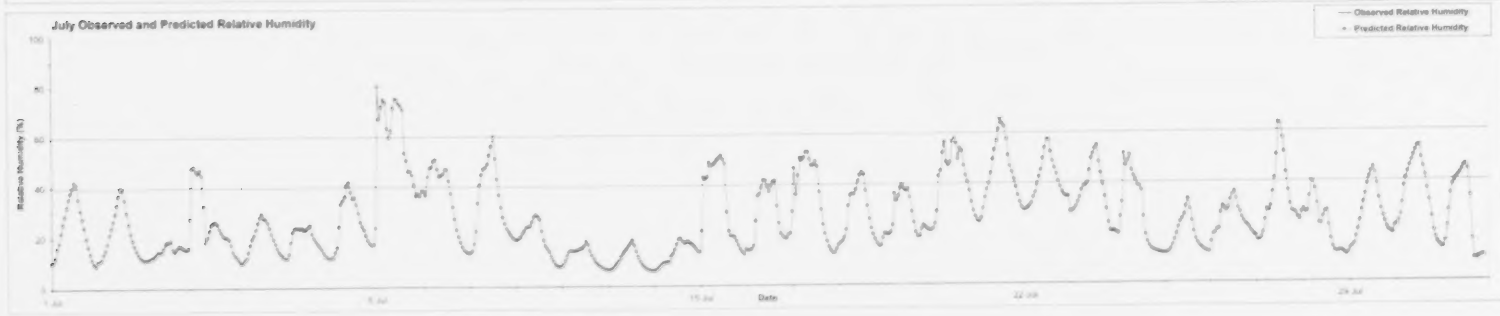


STATION: Great Falls 100m MM5

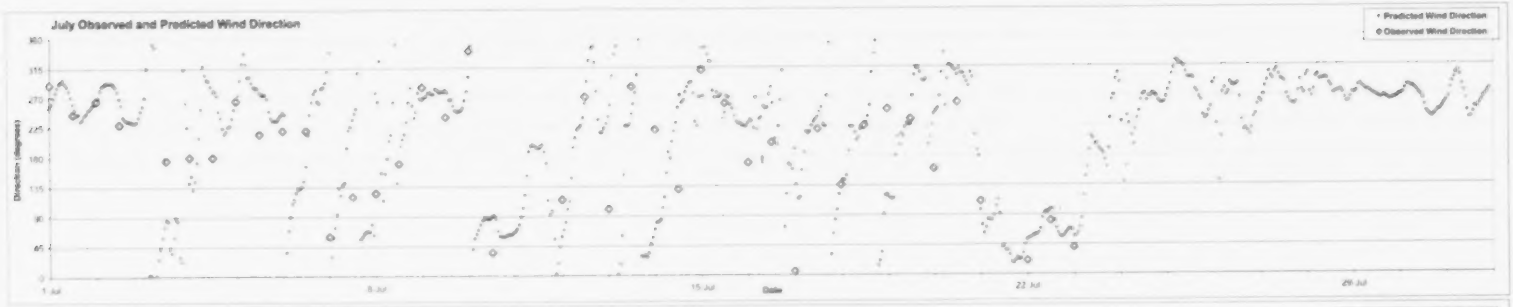


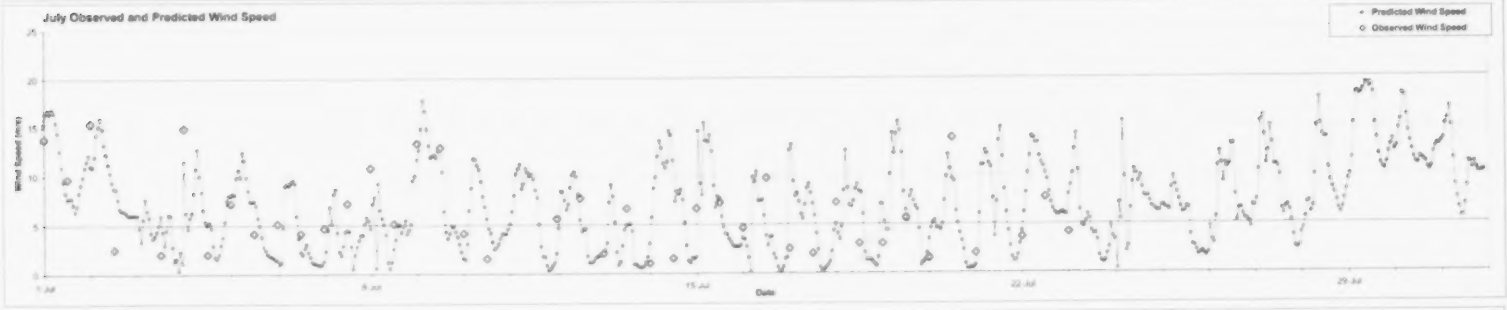


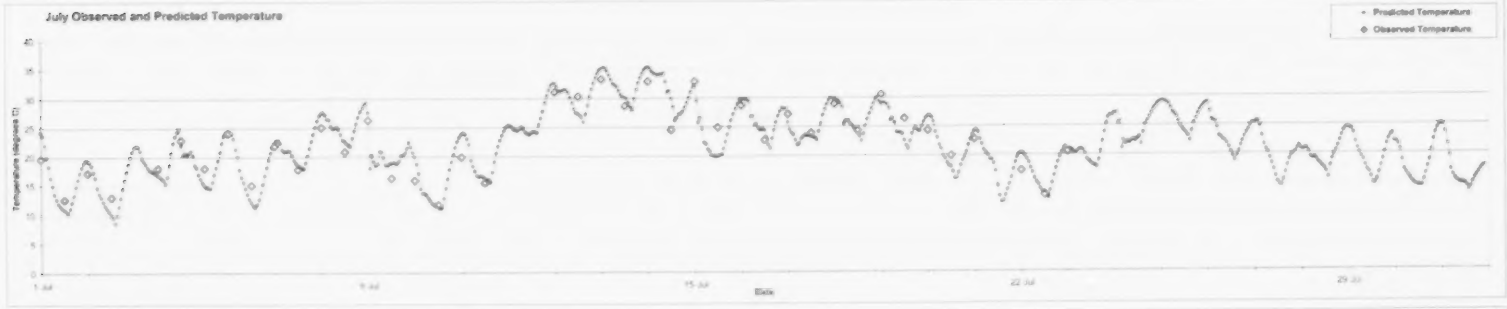


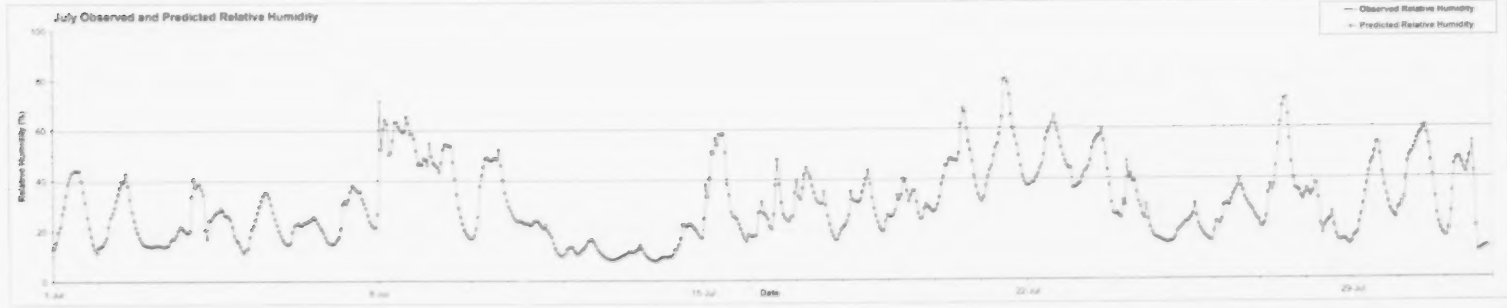


STATION: Great Falls 500m MM5

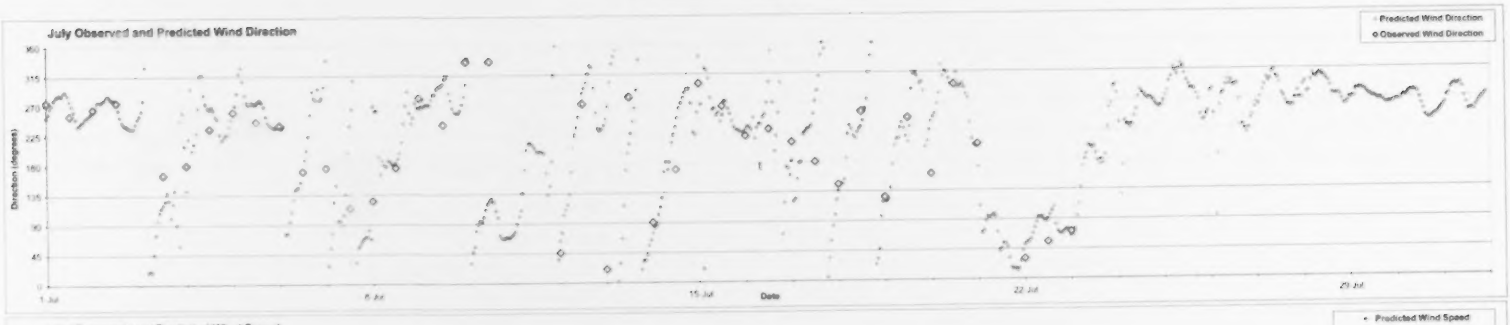


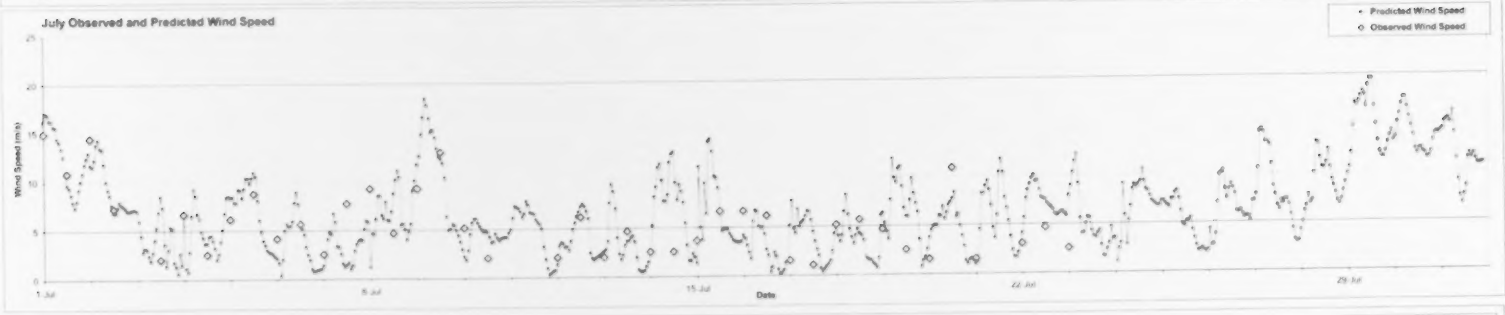


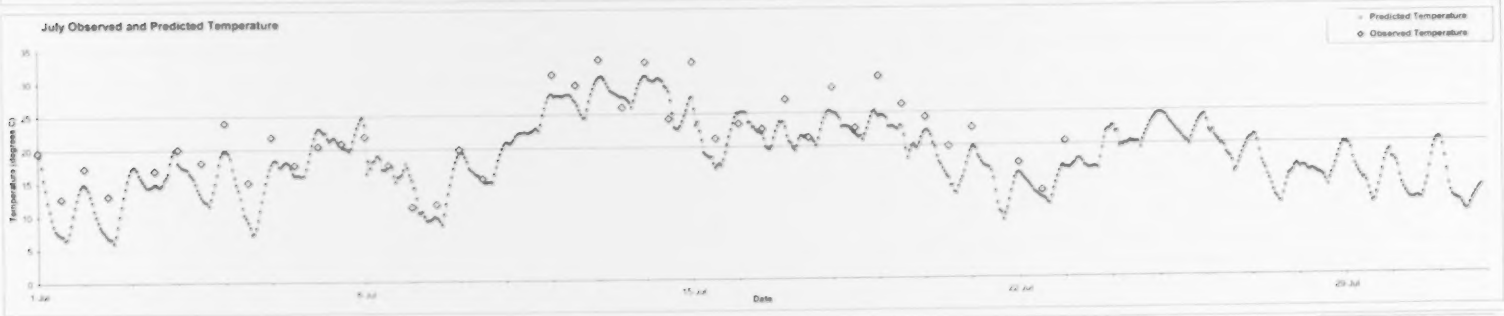


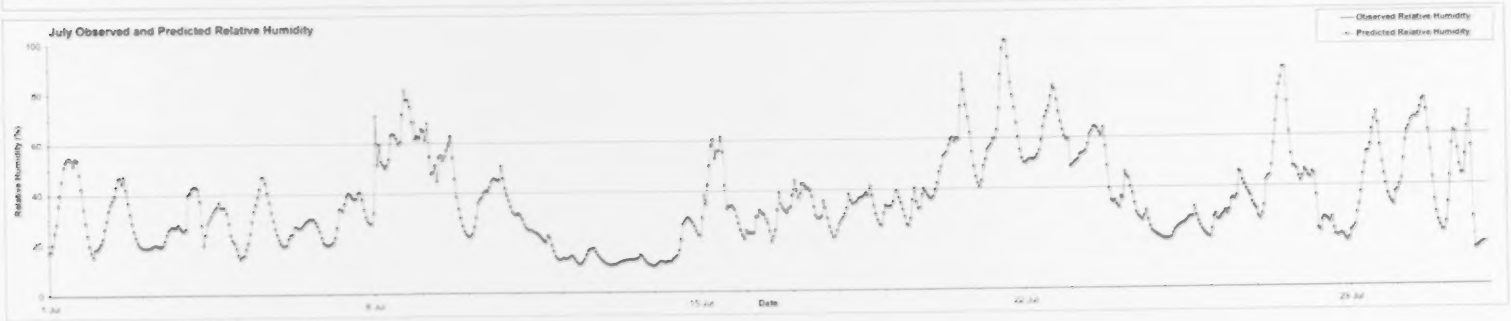


STATION: Great Falls 1000m MM5

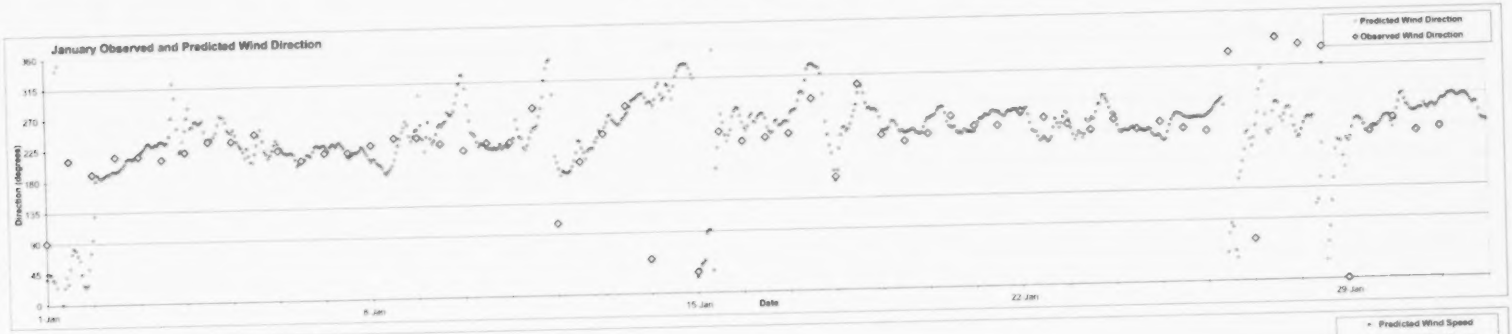


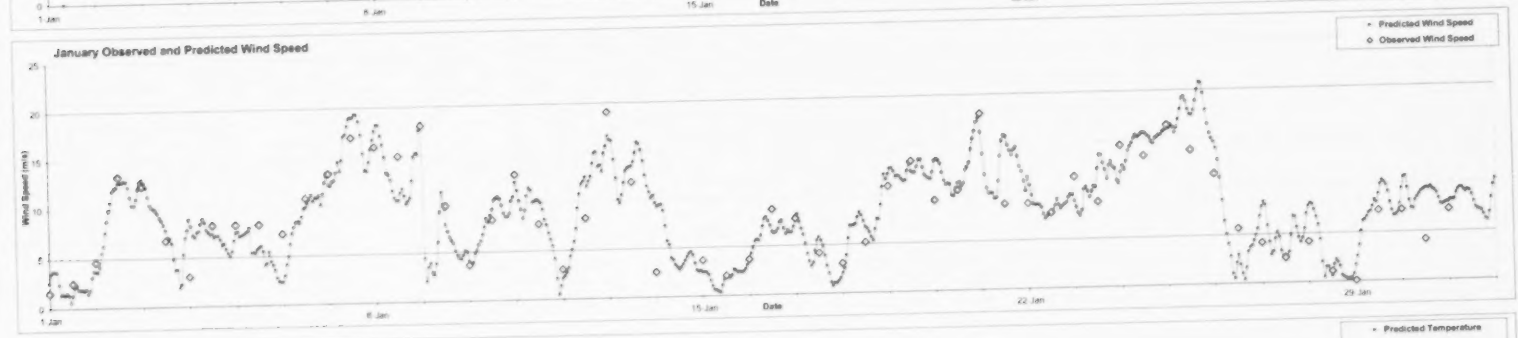


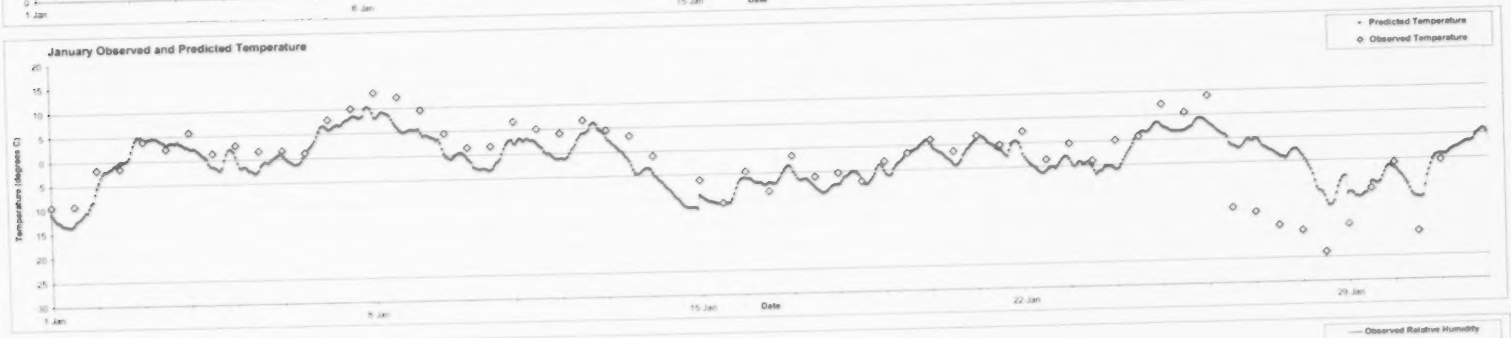


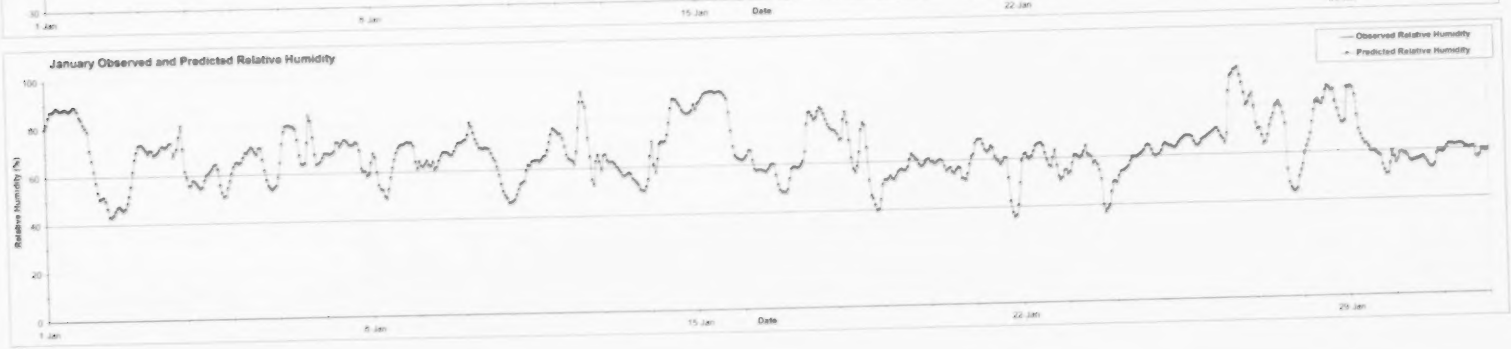


STATION: Great Falls 100m MM5

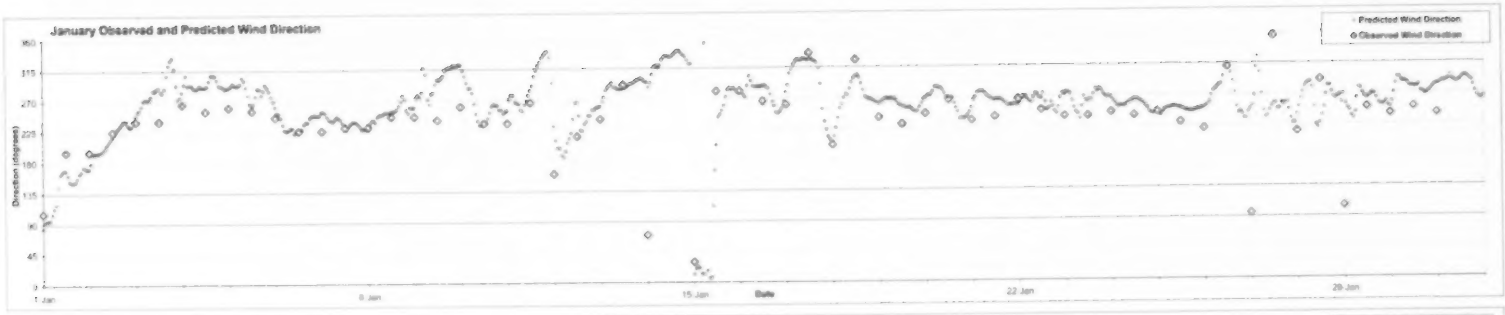


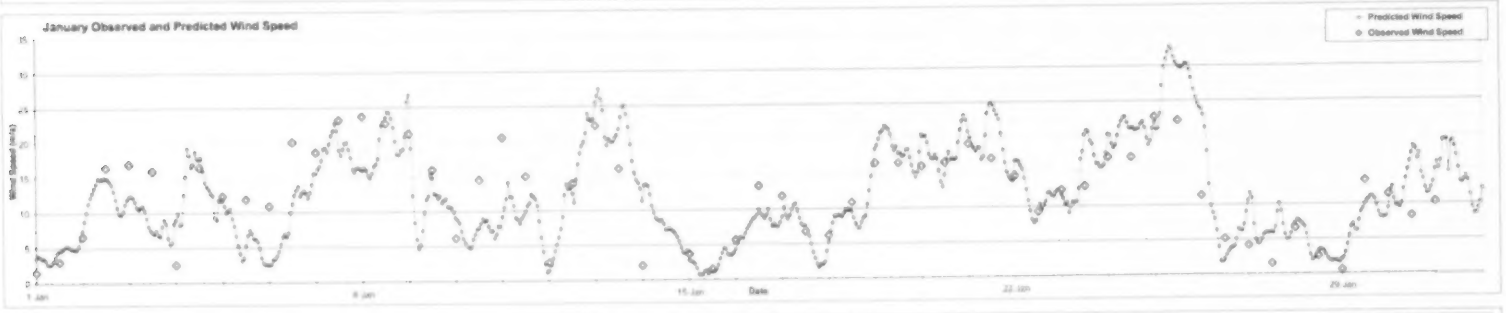


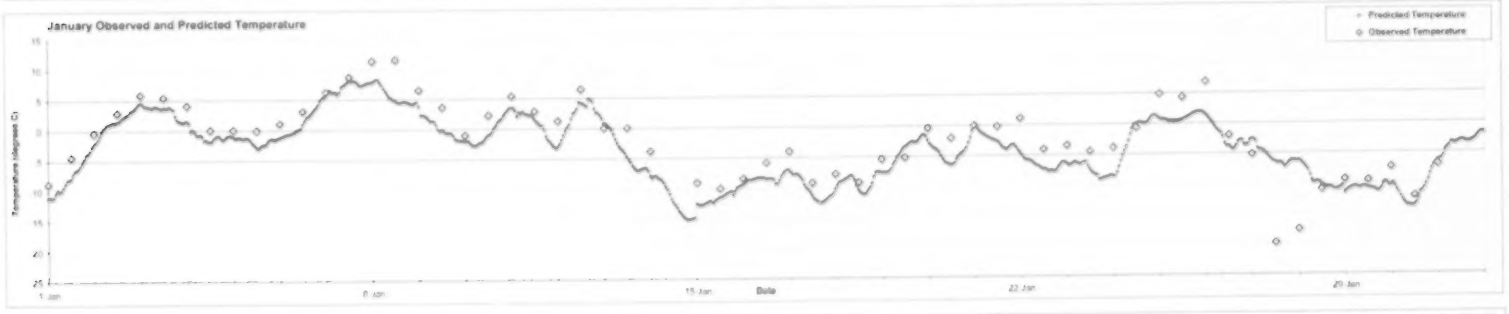


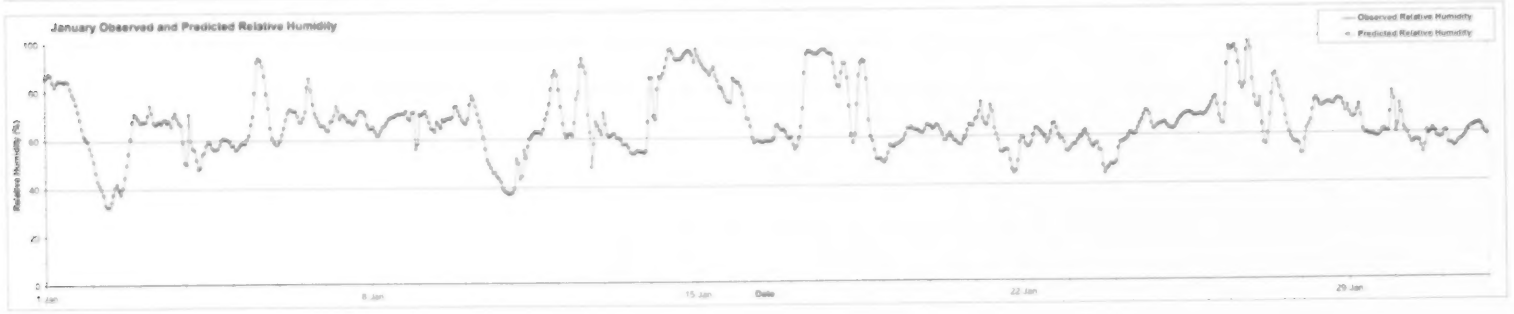


STATION: Great Falls 500m MM5









STATION: Great Falls 1000m MM5